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LECTURES

on the

Steam Engine.

BY THE

REV. DIONYSIUS LARDNER, LL.D.

F.R.S. L.&E. M.R.I.A.

&c. &c.

A New Edition

LONDON.

Printed for John Taylor.
Upper Gower Street

LECTURES

ON

THE STEAM-ENGINE,

IN WHICH
ITS CONSTRUCTION AND OPERATION
ARE FAMILIARLY EXPLAINED:

WITH A SKETCH OF
ITS INVENTION AND PROGRESSIVE IMPROVEMENT,

AND AN ACCOUNT OF
THE PRESENT STATE OF THE LIVERPOOL RAILWAY,
AND THE PERFORMANCES ON IT;

AND OF
STEAM CARRIAGES ON TURNPIKE ROADS.

BY THE REV. DIONYSIUS LARDNER, LL.D.
F.R.S. L. & E. M.R.I.A. F.L.S. &c. &c.

Illuſtrated by Engravings and Woodcuts.

FOURTH EDITION, CONSIDERABLY ENLARGED.

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TO

THE FOURTH EDITION.

The present edition is so much enlarged, by the addition of the tenth and eleventh Lectures, including an account of the Liverpool Railway, and of the preparations for working Steam-Carriages upon turnpike roads, that it may be regarded as a new work, rather than a new edition of the former one. I have neglected no means of obtaining correct information on the subjects included in these two additional sections. On the occasion of a recent visit to the Railway at Liverpool, I was favoured with opportunities of witnessing the performances and capabilities of the engines; and the results of experiments made in my presence are given in the tenth Lecture of the present edition.

I regret that the limits which must necessarily be imposed on a work like the present rendered me unable to avail myself of the mass of valuable information contained in the evidence taken before the House of Commons upon Steam-Carriages more fully than I have done. I have, however, availed myself of it so far, I trust, as to excite those who are interested in the subject to examine the evidence for themselves.

PREFACE

TO

THE FIRST EDITION.

THERE are two classes of persons whose attention may be attracted by a treatise on such a subject as the Steam-Engine. One consists of those who, by trade or profession, are interested in mechanical science, and who therefore seek information on the subject of which it treats, as a matter of necessity, and wish to acquire it in a manner and to an extent which may be practically available in their avocations. The other and more numerous class, is that part of the public in general, who, impelled by choice rather than necessity, think the interest of the subject itself, and the pleasure derivable from the instances of ingenuity which it unfolds, motives sufficiently strong to induce them to undertake the study of it. It is for the use of this latter class principally that the following lectures are designed.

To this class of readers the Steam-Engine is a subject which, if properly treated of, must present strong and peculiar attractions. Whether we consider the history of its invention as to time and place, the effects which it has produced, or the means by which it has caused these effects, we find every thing to gratify our national pride, stimulate our curiosity, excite our wonder, and command our admiration. The invention and progressive improvement of this extraordinary machine, is the work of our own time and our own country; it has been produced and brought to perfection almost within the last century, and is the exclusive offspring of British genius fostered and supported by British capital. To enumerate the effects of this invention, would be to count every comfort and luxury of life. It has increased the sum of human happiness, not only by calling new pleasures into existence, but by

LECTURES

ON

THE STEAM-ENGINE.

portant circumstances in the history of the invention and progressive improvement of this machine, excluding many petty disputes which arose from time to time respecting the rights of invention, the interest of which is buried in the graves of their respective claimants.

In the descriptive parts of the work we have been governed by the same considerations. The application of the force of steam to mechanical purposes, has been proposed on various occasions, in various countries, and under a great variety of forms. The list of British patents alone would furnish an author of common industry and application with matter to swell his book to many times the bulk of this volume. By far the greater number of these projects have however proved abortive. Descriptions of such unsuccessful, though frequently ingenious machines, we have thought it advisable to exclude from our pages, as not possessing sufficient interest for the readers to whose use this volume is dedicated. We have therefore strictly confined our descriptions either to those Steam-Engines which have come into general use, or to those which form an important link in the chain of invention.

Dec. 26. 1827.

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LECTURES

ON

THE STEAM ENGINE.

LECTURE I.

On the Natural Forces which are engaged in different Modifications of the Steam-Engine.

(1.) Of the various productions designed by nature to supply the wants of man, there are few which are suited to his necessities in the state in which the earth spontaneously offers them. If we except air and water we shall scarcely find another instance: even food itself, in most cases, requires culture and preparation. But if, from the mere necessaries of physical existence, we rise to the demands of civil and social life, to say nothing of luxuries and refinements, we find that every thing which contributes to our convenience requires a previous and extensive expenditure of labour. Nay, in most cases, the objects of our enjoyment derive their entire excellence, not from any quality originally inherent in the natural substance out of which they have been formed, but from those qualities which that substance has received from human labour and human skill. Hence have arisen *Manufactures.*

In all the changes to which the raw productions of the earth are submitted in order to suit them to our wants, one of the principal agents is *Motion.*

Thus, for example, in the conversion of wool into clothing for our bodies it is necessary that it should be twisted into threads and then woven into cloth. In these changes *motion* is the agent. To convert the raw wool into thread, a continued rotatory motion must be produced, which being properly communicated, the wool assumes the required form. In like manner, as is well known, particular motions must be given to the threads, in order to produce among them that peculiar arrangement which characterises the texture of the web.

In a rude state of society, the motions required in the infant manufactures are probably communicated by the immediate application of the hand. Observation and reflection, however, soon suggest more effectual means of attaining these ends. When we look around us in the natural world, we perceive various motions actually existing there; we see water falling and wind blowing, and the question instantly arises, whether, without having recourse to animal strength, we may not use these motions for our manufacturing purposes? Here, however, a difficulty is presented. We require motion of a particular kind; but wind will not blow nor water fall as we please, nor as suits our peculiar wants, but according to the fixed laws of nature. We want an *upward* motion; water falls *downward*. We want a circular motion; wind blows in a straight line.

The motions, therefore, which are in actual existence in nature, must be modified, in order to suit our purposes. The means whereby these modifications are produced are called *machines*. A *machine*, therefore, is an instrument interposed between some natural force or motion and the object to which force or motion is desired to be transmitted, and of such construction, that the natural motion is made to produce in that object whatever species of motion it may be required to have.

To give a very obvious example, suppose that a circular or rotatory motion were required to be produced, and that the only natural force at our command were a perpendicular fall of water. A wheel is accordingly provided, furnished with cavities in its rim. The water, in descending, is received into those cavities at one side of the wheel, and being discharged at the lowest point, the cavities ascend empty on the other side. There is thus a load of water always pressing down on one side of the wheel, from which the other side is free, and a constant rotation produced.

In every machine, therefore, the nature and properties of the force from which it derives its motion should be one of the first subjects of consideration. This force, whatever it be, is called the *first mover*.

The first mover used in the steam-engine depends on certain mechanical properties of atmospheric air and of the vapour raised from liquids by heat. A short account of these properties will greatly contribute to the ease with which the action of the machine will be understood. We therefore propose, in the present lecture, to explain the principal properties of air and steam, to which we shall have occasion to allude hereafter.

I. *Of the Mechanical Properties of Air.*

(2.) The ATMOSPHERE is the thin transparent fluid in which we live and move, and which, by respiration, supports animal life. This fluid is apparently so light and attenuated, that it might be at first doubted whether it be really a body at all. It will therefore excite some surprise when we assert not only that it is a body, but also that it is one of considerable *weight*. We shall be able to prove that it presses on every *square inch* * of surface with a weight of about 15lb. avoirdupoise.

(3.) Take a glass tube A B (fig. 2.) more than 32 inches long, open at one end A, and closed at the other end B, and let it be filled with mercury (quicksilver). Let a glass vessel or cistern c, containing a quantity of mercury, be also provided. Applying the finger at A so as to prevent the mercury in the tube from falling out, let the tube be inverted, and the end, stopped by the finger, plunged into the mercury in c. When the end of the tube is below the surface of the mercury in c (fig. 3.) let the finger be removed. It will be found that the mercury in the tube will not, as might be expected, fall to the level of the mercury in the cistern c, which it would do were the end B open so as to admit the air into the upper part of the tube. On the other hand the level D of the mercury in the tube will be about 30 inches above the level c of the mercury in the cistern.

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* As we shall have frequent occasion to mention this magnitude, it would be well that the reader should be familiar with it. It is a *square*, each side of which is an inch. Such as A B C D. Fig. 1.

(4.) The cause of this effect is that the weight of the atmosphere rests on the surface c of the mercury in the cistern and tends thereby to press it up, or rather to resist its fall, in the tube, and as the fall is not assisted by the weight of the atmosphere on the surface D, (since B is closed) it follows that as much mercury remains suspended in the tube above the level c as the weight of the atmosphere is able to support.

If we suppose the section of the tube to be equal to the magnitude of a square inch, the weight of the column of mercury in the tube above the level c will be exactly equal to the weight of the atmosphere on each square inch of the surface c. The height of the level D above c being about 30 inches and a column of mercury two inches in height and having a base of a square inch, weighing about one pound avoirdupois, it follows that the weight with which the atmosphere presses on each square inch of a level surface is about 15lbs. avoirdupoise.

An apparatus thus constructed and furnished with a scale to indicate the height of the level D above the level C is the *common barometer*. The difference of these levels is subject to a small variation which indicates a corresponding change in the atmospheric pressure. But we take 30 inches as a standard or average.

(5.) It is an established property of fluids that they press equally in all directions; and air, like every other fluid, participates in this property. Hence it follows, that since the downward pressure or weight of the atmosphere is about 15lbs. on the square inch, the lateral, upward, and oblique pressures are the same. But independently of the general principle, it may be satisfactory to give experimental proof of this.

Let four glass tubes A, B, C, D, (fig. 4.) be constructed of sufficient length, closed at one end A, B, C, D, and open at the other. Let the open ends of three of them be bent as represented in the tubes B, C, D. Being previously filled with mercury, let them all be gently inverted so as to have their closed ends up as here represented. It will be found that the mercury will be sustained in all, * and that the difference of the levels in all will be the same. Thus the mercury is sustained in A by the upward pressure of the atmosphere, in B by its horizontal or lateral pressure, in C by its downward pressure, and in D by its oblique pressure; and as the difference of the levels is the same in all, these pressures are exactly equal.

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* This experiment with the tube A requires to be very carefully executed and the tube should be one of small bore.

(6.) In the experiment described in (3) the space B D (fig. 3.) the top of the tube from which the mercury has fallen is perfectly void and empty, containing neither air nor any other fluid: it is called therefore a *vacuum*. If, however, a small quantity of air be introduced into that space, it will immediately begin to exert a pressure on D which will cause the surface D to descend, and it will continue to descend until the column of mercury C D is so far diminished that the weight of the atmosphere is sufficient to sustain it, as well as the pressure exerted upon it by the air in the space B D.

The quantity of mercury which falls from the tube in this case is necessarily an equivalent for the pressure of the air introduced, so that the pressure of this air may be exactly ascertained by allowing about one pound per square inch for every two inches of mercury which has fallen from the tube. The pressure of the air or any other fluid above the mercury in the tube, may at once be ascertained by comparing the height of the mercury in the tube with the height of the barometer; the difference of the heights will always determine the pressure on the surface of the mercury in the tube. This principle will be found of some importance in considering the action of the modern steam-engines.

The air which we have supposed to be introduced into the upper part of the tube, presses on the surface of the mercury, with a force much greater than its weight. For example, if the space B D (fig. 3.) were filled with atmospheric air, in its ordinary state it would exert a pressure on the surface D equal to the whole pressure of the atmosphere, although its weight might not amount to a single grain. The property in virtue of which the air exerts this pressure is its elasticity, and this force is diminished in precisely the proportion in which the space it occupies is increased.

Thus it is known that atmospheric air in its ordinary state exerts a pressure on the surface of any vessel in which it is confined amounting to about 15lbs. on every square inch. If the capacity of the vessel which contains it be doubled, it immediately expands and fills the double space, but in doing so it loses half its elastic force and presses only with a force of 7½lbs. on every square inch. If the capacity of the vessel had been enlarged five times, the air would still have expanded so as to fill it, but would exert only a fifth part of its first pressure or 3lbs. on every square inch.

This property of losing its elastic force as its volume or bulk is increased, is not peculiar to air. It is common to all elastic fluids, and we accordingly find it in steam; and it is absolutely necessary to take account of it in estimating the effects of that agent.

(7.) There are numerous instances of the effects of these properties of atmospheric air which continually fall under our observation. If the nozzle and valve-hole of a pair of bellows be stopped, it will require a very considerable force to separate the boards. This effect is produced by the diminished elastic force of the air remaining between the boards upon the least increase of the space within the bellows, while the atmosphere presses with undiminished force on the external surfaces of the boards. If the boards be separated so as to double the space within, the elastic force of the included air will be about 7½lbs. on every square inch, while the pressure on the external surfaces will be 15lbs. on every square inch; consequently it will require as great a force to sustain the boards in such a position, as it would to separate them if each board were forced against the other with a pressure of 7½lbs. on their external surfaces.

When boys apply a piece of moistened leather to a stone, so as to exclude the air from between them, the stone, though it be of considerable weight, may be lifted by a string attached to the leather. The cause of which is the atmospheric pressure, which keeps the leather and the stone in close contact.

I. *Of the Mechanical Properties of Vapor.*

(8.) If we expose our body to the effects of fire, we feel a certain sensation which we call *heat.* The matter, or whatever it be which causes this sensation, is properly called *caloric.* But in familiar discourse, heat and caloric are used indifferently.

Caloric is known to pervade all bodies in nature, in a greater or lesser degree; and the quantity of it in any substance may be increased or diminished within certain limits. The increase of the quantity of caloric in a body, is in general attended with an increase of its bulk, and the diminution of it with a corresponding diminution of bulk. Thus metals expand or enlarge their dimensions when heated, and contract when cooled. A flaccid bladder containing a small quantity of air, will when heated become quite distended, owing to the expansion of the air contained in it, but will again resume its flaccid appearance when cooled. And the same is true of all substances.

(9.) So universal is this law of expansion, that it has been actually taken as the measure of the *degree* of heat, and is the principle on which *thermometers* are constructed. Some mercury is enclosed in a glass ball, to which a tube is attached, so that when heat is applied to the ball, the expansion of the metal it contains, forces mercury up in the tube, which being applied to a graduated scale, becomes the measure of temperature, by means of the expansion which that temperature produces.

(10.) Expansion or enlargement of dimension is not, however, the only effect which attends increasing the quantity of caloric in a body. In some cases a total change of form is effected by it. If a superabundant quantity of caloric be given to a piece of solid metal, it will be converted into a liquid. The metal in this case is said to be *fused,* and the process is called *fusion.*

So long as the requisite temperature is kept up and caloric supplied in a sufficient quantity, so long will the metal retain its liquid state; but when that supply is withdrawn, and the temperature lowered, it again resumes its solid form.

Again, if from any substance, as water, which is usually in the liquid state, a considerable portion of caloric be withdrawn, and the temperature lowered, it will at length become solid, and will remain so until the caloric be restored, when it will again resume its liquid form.

From these and numerous other similar circumstances we conclude that all the substances in nature which we observe in the solid or the liquid state, are retained in their respective forms by the agency of caloric.

(11.) The reciprocal changes, liquefaction and solidification, are not the only changes in the form of substances which are produced by a change in their temperature. If heat be communicated to a liquid, as water, the first effect will be to raise its temperature and to enlarge its bulk. But after the temperature has been raised to about 212 degrees of the common thermometer, no further accession of heat will be perceived, and the thermometer placed in it will cease to rise. Nevertheless, heat will be communicated to the water, and the vessel which contains it. What then, it may be asked, becomes of this heat? In this state the water will be in a rapid state of evaporation, or of being converted into steam, and all the heat which is communicated to it in addition to what is indicated by the thermometer, is consumed in the formation of this steam. Hence it appears that under ordinary circumstances,* water cannot maintain its liquidity at a temperature higher than 212°, and that any additional heat beyond what is necessary to give it this temperature, will convert a part of it into steam.

It appears, therefore, that the quantity of caloric in a liquid, being sufficiently increased, it will at length be converted into a vapor, or changed from an inelastic fluid into an elastic one, and will thus totally change its mechanical character by the acquisition of the property of elasticity already described in air (6). On the other hand, if from elastic vapor the heat be abstracted, it will be again restored to its liquid state, it being incapable of existing, under ordinary circumstances, in the vaporous form, at a lower temperature than 212°.

From all these circumstances we infer, that bodies are retained in the several states of solid, liquid and vapor by the agency of heat, and that the same body may be passed successively through these several states, by a proper change in the caloric which is transfused through its dimensions.

(12.) We have stated that when the increase or diminution of temperature does not change the *form* of a body, it changes its dimensions or bulk. This effect is not confined to solids and liquids, but is found still more perceptibly in vapors and all elastic fluids.

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* Under particular circumstances water can maintain its liquidity at any temperature, as will appear hereafter.

If a small quantity of air be included in a flaccid bladder tied at the mouth, so as to be air-tight; when the bladder is held before a fire, it will become distended, and have all the appearance of being inflated. The cause of which obviously is the dilatation of the air contained in it, by the increased temperature which it has acquired.

Again, let a tube A B (fig. 5.) open at both ends, have one end inserted in the neck of a vessel C D, containing a coloured liquid with common air above it, and let the tube be fixed so as to be air tight in the neck. Upon heating the vessel the warm air above the level C D will begin to expand, and will press on the surface of the coloured liquid, so as to force it up in the tube A B.

(13.) The same elastic fluid, whether it be a gas or a vapor, has always, at the same temperature and density, the same degree of elastic force, but if either the temperature or the density, or both, be increased, the elastic force is also increased. Therefore the elastic force depends conjointly on the temperature and the density.

(14.) All the effects of caloric which we have just described, may be very satisfactorily accounted for by supposing that it is a substance or a cause imparting to the corpuscles of bodies a repulsive force, by which they acquire a tendency to repel each other. But in conjunction with this, it is necessary to attend to another force which is known to exist in nature. There is observable amongst the constituent particles of every body, a force in virtue of which they have a tendency to cohere and collect themselves together in concrete solid masses. This tendency is called *cohesion*, or the *attraction of cohesion*. This cohesive force in the particles of matter is directly counteracted by the effects of *caloric*. It is supposed by some that caloric is an highly elastic and very subtle fluid, that transfuses itself through the dimensions of all bodies, and by its elastic force tends to separate and force asunder their particles, and to dissolve the union which the *cohesive* force tends to produce. It is however certain, whatever be the nature of caloric, that it gives to the particles a tendency, the very opposite of cohesion, and that the state of a body, whether solid or liquid, must be decided by the relation between the two forces, viz. the cohesive force natural to its particles, and the repulsive force dependent on the caloric which pervades them. If the cohesion of the particles predominate considerably over the repulsive force of the caloric, the state of the body will be *solid;* if however these forces nearly neutralise each other, it will be *liquid.*

As to mutual cohesion, the particles of a liquid may therefore be considered as *nearly* in a state of indifference. We say *nearly*, because in most liquids a slight tendency to cohesion may be perceived. Thus, if two drops of mercury or water be placed on a glass plate near each other, they will immediately unite and form one drop. But in a general way, and merely in a mechanical point of view, we may regard the parts of liquids to be in a state of indifference as to cohesion.

(15.) By tracing up the analogy which we have commenced, on the effects of the cohesive and repulsive forces incident to the particles of bodies, we would be led to conclude, that by increasing the latter until it greatly predominated over the former, the particles of the body would have as strong a tendency to separate from each other, as they have to collect together, when the opposite relation exists between these two forces; and such in fact we find to be the case. If sufficient heat be communicated to a *liquid*, it will be, as we have before stated, converted into *vapor*, the particles of which repel each other, so that it tends to burst any vessel in which it may be confined. Thus, then, we may account for the existence of the gaseous state, or of what is called *elastic fluids*, the cohesive force natural to the particles of the body is not only overcome by the repulsive force introduced by the caloric, but a strong repulsive influence is given to the particles, so that they endeavour to separate from each other, and to expand continually into an increased bulk, if not resisted by an adequate force.

Thus, if water be exposed to heat until it boil, it will be converted gradually into steam. If this steam be enclosed in any vessel, it will tend to burst its sides with a certain elastic force, exactly in the same manner as air would, if similarly confined. But an effect is observed in the conversion of liquids into vapor by heat, which is not perceptible in the conversion of solids into liquids. We have said that these several states depend on the mutual proportion of the cohesive and repulsive forces of the particles. There is, however, a third force which always assists the cohesion, to be taken into account, and the effects of which are very apparent in vaporization, although not in liquefaction. This force is the *atmospheric pressure* already described. This evidently tends to press together the parts of a body, and, therefore, assists cohesion. Thus if water be placed in a vessel, and have its surface exposed to the atmosphere when the barometer stands at 30 inches, it will sustain a pressure on its surface amounting to 15lbs. on every square inch. This force in addition to cohesion must be overcome by the repulsive effect of the caloric, before vaporization can commence. By reasoning thus we would be led directly to two conclusions: 1°. that if the atmospheric pressure were removed or diminished, liquids would boil with less heat or at a lower temperature: and 2°. that if the pressure on the surface were increased, they will not boil until a proportionably increased heat be given them, or until they attain a much higher temperature. These inferences we accordingly find supported by experience. Under a pressure of 15lbs. on the square inch, i. e. when the barometer is at 30 inches, water boils at the temperature of 212° of the common thermometer. But if water at a lower temperature, suppose 180°, be placed under the receiver of an air-pump, and, by the process of exhaustion, the atmospheric pressure be removed, or very much diminished, the water will boil, although its temperature still remain at 180° as may be indicated by a thermometer placed in it.

(16.) On the other hand, if a thermometer be inserted air-tight in the lid of a close digester containing water with common atmospheric air above it, when the vessel is heated the air acquires an increased elasticity, and being confined by the cover, presses with increased force on the surface of the water. By observing the thermometer while the vessel is exposed to the action of heat, it will be seen to rise considerably above 212°, suppose to 280°, and would continue so to rise until the strength of the vessel could no longer resist the pressure within it.

(17.) The temperature at which water boils is commonly said to be 212°, which is called *the boiling point* of the thermometer, but strictly speaking this is only true when the barometer stands at 30 inches. If it be lower, water will boil at a lower temperature, because the atmospheric pressure is less, and if it be higher, as at 31, water will not boil until it receive an higher temperature, the pressure being greater.

According as the cohesive forces of the particles of liquids are more or less active, they boil at greater or lesser temperatures. In general the lighter liquids such as *alcohol* and *ether* boil at lower temperatures. These fluids in fact would boil by merely removing the atmospheric pressure as may be proved by placing them under the receiver of an air pump and withdrawing the air. From this we may conclude that these and similar substances would never exist in the liquid state at all, but for the atmospheric pressure.

(18.) The elasticity of vapor raised from a boiling liquid, is equal to the pressure under which it is produced. Thus, steam raised from water at 212°, and, therefore, under a pressure of 15lbs. on the square inch is endued with an elastic force which would exert a pressure on the sides of any vessel which confines it, also equal to 15lbs. on the square inch. Since an increased pressure infers an increased temperature in boiling, it follows that where steam of a higher pressure than the atmosphere is required, it is necessary that the water should be boiled at an higher temperature.

(19.) We have already stated that there is a certain point at which the temperature of a liquid will cease to rise, and that all the heat communicated to it beyond this is consumed in the formation of vapor. It has been ascertained that when water boils at 212°, under a pressure equal to 30 inches of mercury, a cubic inch of water forms a cubic foot* of steam, the elastic force of which is equal to the atmospheric pressure, and the temperature of which is 212°. Since there are 1728 cubic inches in a cubic foot, it follows that when water at this temperature passes from the liquid to the vaporous state it is dilated into 1728 times its bulk.

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* The terms *cubic inch* and *cubic foot* are easily explained. A common die, used in games of chance, has the figure which is called a cube. It is a solid having twelve straight edges equal to one another. It has six sides, each of which is square, and which are also equal to one another. If its edges be each one inch in length, it is called a *cubic inch*, if one foot, a *cubic foot*, if one yard, a *cubic yard*, &c. This figure is represented in perspective, in fig. 6.

(20.) There are several circumstances which would lead us to suspect that a considerable absorption of heat is necessary for the process of vaporization. It is observed in general that expansion is an indication of the acquisition of heat, and in this case it appears that there is an expansion producing an increase of bulk in the proportion of 1728 to one. Again, it may be observed that all the heat given to the liquid after it has reached the boiling point is spent in vaporization, and yet it takes six times as long to convert a given quantity of water into steam at 212° as to raise the same quantity from the freezing (32°) to the boiling point. Hence we may infer that, supposing the application of heat to be uniform, it takes six times as much heat to convert any quantity of water at 212° into steam as to raise the same quantity from 32° to 212°. Or what amounts to the same thing, it takes as much heat to convert any quantity of water at 212° into steam as would raise six times that quantity from 32° to 212°.

Another way of representing this striking fact is, that if one cubic inch of water in a state of vapor at 212° be *mixed* with six cubic inches of water at 32°, the whole mass will form 7 cubic inches of water at 212°. Thus the redundancy of heat necessary to retain the water in the state of vapor, is sufficient to raise the six cubic inches from 32° to 212°.

A cubic foot of steam raised from water at 212° will itself have only the same temperature, 212°. We are, therefore, to conclude that all the additional heat which has been given to it in the process of vaporization is engaged in giving it the elastic form, and being insensible to the thermometer is called *latent heat.* From the facts just mentioned, the immense expenditure of heat in the production of steam must be quite apparent.

Since the temperature at which water boils depends on the pressure to which it is submitted, it is manifest that there is no other limit to the temperature of which it is susceptible except that of the mechanical pressure to which we are able to submit it. We shall see hereafter that it is capable of being raised to 600°, 700°, or 800°. In fact, that it may be rendered *red-hot.*

The temperature of steam may be changed after it assumes the vaporous form. Thus, steam raised from water at 180° may subsequently be raised to 212°. But the steam thus obtained at the temperature of 212° will not have a pressure equal to that obtained immediately from water boiled at 212°; the pressure of the former will be considerably less than that of the latter.

(21.) As a liquid is converted into vapor by imparting to it a superabundant supply of caloric, so also a vapor may be restored to the liquid state by withdrawing from it a sufficient portion of caloric. If a close vessel be filled with steam, and then a jet of cold water be forced into it, the water will immediately draw a quantity of heat from the steam,which will be reduced to water, and will fall in that form on the bottom of the vessel. The same property is also manifested by allowing steam to come in contact with any cold surface. Let any body be held before the steaming spout of a tea-kettle and it will presently become wet. This moisture is the steam reconverted into water by losing part of its heat and resting on the body. This reconversion of steam into water by the abstraction of heat is called *condensation.*

By this property, steam is rendered instrumental in the formation of a *vacuum.* By allowing steam to circulate through a vessel, the air may be expelled from it, and its place filled by steam. If the vessel be then closed and cooled, the steam will be reduced to water, and, falling in drops on the bottom and sides of the vessel, the space which it filled will become a *vacuum.* This may be easily established by experiment. Let a long glass tube be provided with a hollow ball at one end, and having the other end open.* Let a small quantity of spirits be poured in at the open end, and placing the glass ball over the flame of a lamp, let the spirits be boiled. After some time the steam will be observed to issue copiously from the open end of the tube which is presented upwards. When this takes place, let the tube be inverted, and its open end plunged in a bason of cold water. The heat being thus removed, the cool air will reconvert the steam in the tube to liquid, and a vacuum will thus be produced so that the pressure of the atmosphere on the surface of the water in the bason will force the water thro' the tube, and it will rush up with considerable force, and fill the glass ball.

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* A common glass flask with a long neck will answer the purpose.

In this experiment it is better to use spirits than water, because they boil at a lower heat, and expose the glass to less liability to break, and also the tube may more easily be handled.

LECTURE II.

Invention of the Steam-Engine — Claims of the Marquess of Worcester — Captain Savery. Description of the Steam Engine constructed by him, and its method of operation.

(22.) CLAIMS to the invention of the STEAM-ENGINE have been advanced by various nations, and by various individuals of the same nation. The partisans of the competitors for this honour have urged their pretensions and pressed their claims with a zeal strongly tinctured with prejudice both national and personal; and the contentions have, in some instances, been marked with a degree of asperity unworthy ot the cause in which they engaged, and altogether beneath the dignity of science.

The steam-engine, as it exists at present, is not the exclusive invention of any one individual; it is a combination of inventions which, for the last two centuries, have been accumulating. When we attempt to trace back its history and to determine its first inventor, we experience the same difficulty as is felt in ascertaining the head of a great river: as we ascend its course, it becomes difficult if not impossible to distinguish it from its tributary streams, and it terminates in a number of threads of water, each in itself so insignificant as to seem unworthy of being called the source of the majestic object which has excited the inquiry.

The mere fact that the steam of boiling water is capable of producing motion must have been observed at a very early period. No one could look at a close vessel of water boiling, and observe the force with which the steam issues from its spout without, at once, perceiving the possibility of producing motion in any light substance exposed to its action. Yet trifling as this circumstance must appear, it has formed the sole foundation for some claims which have been advanced to the invention of the present steam-engine.*

(23.) The use of the *elastic* force of steam, as a first mover in a machine designed for raising water, was proposed by EDWARD SOMERSET, MARQUESS OF WORCESTER, in a work intitled "a Century of Inventions," published in the year 1683. The following is the description which is given in that work of the contrivance:

"I have invented an admirable and forcible way to draw up water by fire; not by drawing or sucking it upwards, for that must be, as the philosopher terms it, *intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder if the vessel be strong enough. For I have taken a piece of whole cannon whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end, as also the touch-hole and making a constant fire under it; within twenty four hours, it burst and made a great crack. So that, having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other; I have seen the water run like a constant stream forty feet high. One vessel of water rarefied by fire driveth up forty of cold water, and a man that tends the work has but to turn two cocks; that one vessel of water being consumed another begins to force and refill with cold water and so successively; the fire being tended and kept constant, which the self same person may likewise abundantly perform in the interim between turning the said cocks."

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* The invention has been claimed for Branca, an Italian philosopher, who proposed turning the vanes of a mill by a steaming kettle.

The Marquess states that these experiments were made about 1663. We have, however, no evidence, except his own statement, that he ever constructed the machine or made the experiments above described; and for this reason, some writers on the subject have denied him any share in the discovery of the steam-engine, while others, falling into the opposite extreme give him the entire honor of being its first inventor.

Whether the Marquess of Worcester ever tried these experiments or constructed the machine he alludes to is, we conceive, a matter of perfect and absolute indifference as to the share to which he may be considered to be intitled in the invention of the steam-engine. It is quite clear that, in the passage we have quoted, he distinctly points out the pressure arising from the elastic force of steam as a mechanical agent. He gives an instance of the possibility of applying it to elevate water, and mentions the advantage which, in this respect, it possesses over the atmospheric pressure, viz. that the latter has a limit, not being capable of supporting more than about 34 feet of water, while the pressure of steam has no other limit than the strength of the vessels which contain it. Had he merely stated these things, without alleging, as he does, that he had actually tried the experiment, he would, we conceive, have an undeniable claim to the merit of having first suggested the elastic force of steam as a mechanical agent of a power almost unlimited, and beyond this, even had he made his experiment publicly, his claim could not be admitted; for it is certain that no engine constructed in the manner to which he alludes, could be rendered extensively useful as a machine even for raising water, as we shall see hereafter.

(24.) No further discovery in the mechanical application of steam, appears to have been made until about the year 1698, when the method of producing a vacuum by the condensation of steam (described in 21) was discovered by Captain SAVERY, who, combining this with the application of the elastic force suggested by the Marquess of Worcester, constructed an engine for raising water, for which he was granted a patent.

Savery states that his discovery of the condensing principle arose from the following circumstance. Having drunk a flask of Florence at a tavern, he called for a bason of water to wash his hands, and flung the empty flask on the fire. A small quantity of wine which remained in the flask began to boil, and steam issued from its mouth. It occurred to him, to try what effect would be produced by inverting the flask and plunging its mouth in the cold water. Putting on a thick glove to defend his hand from the heat, he did so, and immediately the water in the bason rushed up into the flask and filled it. (See (21)).

This circumstance suggested to Savery the possibility of giving effect to the atmospheric pressure, by creating a vacuum in this manner. If, instead of exhausting the barrel of a pump by the usual laborious method of a piston and sucker, it were exhausted by first filling it with steam, and then condensing the same steam, the atmospheric pressure would force the water in the well up into the pump-barrel, and into any vessel connected with it, provided that vessel were not more than 34 feet above the level of the water in the pump-well. Savery also plainly saw, that this water might be forced to a still greater elevation by using the elastic force of steam upon the Marquess of Worcester's principle, and that this very steam would serve by its subsequent condensation to repeat the vacuum, and draw up more water. On these principles Savery constructed his steam-engine.

(25.) In this, and indeed every steam-engine, there are two parts; 1°. that which is employed in generating the steam (the *boiler*); and 2°. that in which the steam is applied as a moving power, (the *working apparatus*). We shall first describe the former apparatus in Savery's engine.

The sections of two strong boilers D E, are represented in fig. 7, D the greater and E the less. The tubes T and T′ communicate with the working apparatus which we shall presently describe. A thin plate of metal R is applied closely to the top of the principal boiler D turning on a centre C, so that by moving a lever applied to the axis C on the outside of the top, the sliding plate R can be brought from the mouth of the one tube to the mouth of the other alternately. This sliding valve is called the *regulator*, since it is by it that the communications between the boiler and two steam vessels (hereafter described,) are alternately opened and closed, the lever which effects this being constantly wrought by the hand of the attendant.

Two *gauge pipes* are represented at G, G′, the use of which is to determine the depth of water in the boiler. One G has its lower aperture a little above the proper depth, and the other G′ a little below it. Cocks are attached to the upper ends G, G′, which can be opened or closed at pleasure. The steam collected in the top of the boiler pressing on the surface of the water forces it up in the tubes G, G′, if their lower ends be immersed. Upon opening the cocks G, G′, if water be forced from both, there is too much water in the boiler, since the mouth of G is *below* its level. If steam issue from both there is too little water in the boiler, since the mouth of G′ is *above* its level. But if steam issue from G and water from G′ the water in the boiler is at its proper level. This ingenious contrivance for determining the level of the water in the boiler is the invention of Savery, and is used in many instances at the present day.

The mouth of G should be at a level of a little less than one-third of the whole depth, and the mouth of G′ at a level a little lower than one third; for it is requisite that about two thirds of the boiler should be kept filled. The tube I forms a communication between the principal boiler D and the subsidiary or feeding boiler E descending nearly to the bottom of it. This communication can be opened and closed at pleasure by the cock K. A gauge pipe is inserted similar to G, G′ but extending nearly to the bottom. From this boiler a tube F extends which is continued to a cistern C (fig. 8.) and a cock is placed at M which, when opened, allows the water from the cistern to flow into the feeding boiler E, and which is closed when that boiler is filled. The manner in which this cistern is supplied will be described hereafter.

Let us now suppose that the principal boiler is filled to the level between the gauge pipes, and that the subsidiary boiler is nearly full of water, the cock K and the gauge cocks G G′ being all closed. The fire being lighted beneath D and the water boiled, steam is produced and is transmitted through the tubes T T′, to the working apparatus. When evaporation has reduced the water in D below the level of G′ it will be necessary to replenish the boiler D. This is effected thus. A fire being lighted beneath the feeding boiler E, steam is produced in it above the surface of the water, which having no escape presses on the surface so as to force it up in the pipe I. The cock K being then opened, the boiling water is forced into the principal boiler D, into which it is allowed to flow until water issues from the gauge cock G′. When this takes place, the cock K is closed, and the fire removed from E until the great boiler again wants replenishing. When the feeding boiler E has been exhausted, it is replenished from the cistern C (fig. 8.) through the pipe F by opening the cock M.

(26.) We shall now describe the working apparatus in which the steam is used as a moving power.

Let V V′ (fig. 8.) be two steam-vessels communicating by the tubes T T′ (marked by the same letters in fig. 7.) with the greater boiler D.

Let S be a pipe, called the *suction pipe,* descending into the well or reservoir from which the water is to be raised, and communicating with each of the steam-vessels through tubes D D′ by valves A A′ which open upwards. Let F be a pipe continued from the level of the engine of whatever higher level it is intended to elevate the water. The steam vessels V V′ communicate with the *force pipe* F by valves B B′ which open upward, through the tubes E E′. Over the steam vessels and on the force pipe is placed a small cistern C already mentioned which is kept filled with cold water from the pipe and from the bottom of which proceeds a pipe terminated with a cock G. This is called the *condensing pipe* and can be brought alternately over each steam-vessel. From this cistern another pipe communicates with the feeding boiler (fig. 7.), by the cock M.*

The communication of the pipes T T′ with the boiler can be opened and closed, alternately, by the regulator R, (fig. 7.) already described.

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* This pipe in fig. 9. is represented as proceeding from the force-pipe above the cistern C.

Now suppose the steam-vessels and tubes to be all filled with common atmospheric air and that the regulator be placed so that the communication between the tube T and the boiler be opened, the communication between the other tube T′ and the boiler being closed. Steam will flow into V through T. At first, while the vessel V is cold, the steam will be condensed and will fall in drops of water on the bottom and sides of the vessel. The continued supply of steam from the boiler will at length impart such a degree of heat to the vessel V that it will cease to condense it. Mixed with the heated air contained in the vessel V, it will have an elastic force greater than the atmospheric pressure, and will therefore force open the valve B through which a mixture of air and steam will be driven until all the air in the vessel V will have passed out, and it will contain nothing but the pure vapor of water.

When this has taken place, suppose the regulator be moved so as to close the communication between the tube T and the boiler, and to stop the further supply of steam to the vessel V; and at the same time let the condensing pipe G be brought over the vessel V and the cock opened so as to let a stream of cold water flow upon it. This will cool the vessel, and the steam with which it is filled will be condensed and fall in a few drops of water, leaving the interior of the vessel a vacuum. The valve B will be kept closed by the atmospheric pressure. But the elastic force of the air between the valve A and the surface of the water in the well, or reservoir, will open A so that a part of this air will rush in (21) and occupy the vessel V. The air in the suction pipe S, being thus allowed an increased space, will be proportionably diminished in its elastic force (6) and its pressure will no longer balance that of the atmosphere acting on the external surface L * of the water in the reservoir. This pressure will, therefore, force water up in the tube S until its weight, together with the elastic force of the air above it, balances the atmospheric pressure on L (4). When this has taken place, the water will cease to ascend.

Let us now suppose that, by shifting the regulator, the communication is opened between T and the boiler, so that steam flows again into V. The condensing cock G being removed, the vessel will be again heated as before, the air expelled, and its place filled by the steam. The condensing pipe being again allowed to play upon the vessel V, and the further supply of steam being stopped, a vacuum will be produced in V, and the atmospheric pressure on L will force the water through the valve A into the vessel V which it will nearly fill, a small quantity of air however remaining above it.

Thus far the mechanical agency employed in elevating the water is the atmospheric pressure; and the power of steam is no further employed than in the production of a vacuum. But, in order to continue the elevation of the water through the force pipe F, above the level of the steam-vessel, it will be necessary to use the elastic pressure of the steam. The

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* Not in the diagram.

vessel v is now nearly filled by the water which has been forced into it by the atmosphere. Let us suppose that the regulator being shifted again, the communication between the tube T and the boiler is opened, the condensing cock removed, and that steam flows into V. At first coming in contact with the cold surface of the water and that of the vessel, it is condensed; but the vessel is soon heated, and the water formed by the condensed steam collects in a sheet or film on the surface of the water in V, so as to form a surface as hot as boiling water.* The steam then being no longer condensed, presses on the surface of the water with its elastic force and when that pressure becomes greater than the atmospheric pressure, the valve B is forced open and the water, issuing through it, passes through E into the force pipe F and this is continued until the steam has forced all the water from V, and occupies its place.

The further admission of steam through T is once more stopped by moving the regulator, and the condensing pipe being again allowed to play on V, so as to condense the steam which fills it, produces a vacuum. Into this vacuum, as before, the atmospheric pressure on L will force the water and fill the vessel V. The condensing pipe being then closed and steam admitted through T, the water in V will be forced by its pressure through the valve B and tube E into F, and so the process is continued.

We have not yet noticed the other steam vessel V′ which, as far as we have described, would have remained filled with common atmospheric air, the pressure of which, on the valve A′, would have prevented the water raised in the suction pipe S from passing through it. However, this is not the case · for, during the entire process which has been described in V, similar effects have been proceeding in V′, to which I have only omitted to solicit your notice, to avoid the confusion which the two processes might produce. It will be remembered, that after the steam, in the first instance, having flowed from the boiler through T, has blown the air out of V through B, the communication between T and the boiler is closed. Now the same motion of the regulator which closes this, opens the communication between T′ and the boiler; for the sliding plate R (fig. 7.) is moved from the one tube to the other, and at the same time, as we have already stated the condensing pipe is brought to play on V. While, therefore, a vacuum is being formed in V by condensation, the steam, flowing through T′, blows out the air through B′, as already described in the other vessel V; and, while the air in S is rushing up through A into V followed by the water raised in S by the atmospheric pressure on L, the vessel V′ is being filled with steam, and the air is completely expelled from it.

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* Hot water being lighter than cold, floats on the surface.

The communication between T and the boiler is now again opened, and the communication between T′ and the boiler closed by moving the regulator R (fig. 7.) from the tube T to T′; at the same time the condensing pipe is removed from over V and brought to play upon V′. While the steam once more expels the air from V through B, a vacuum is formed by condensation in V′, into which the water in S rushes through the valve A′. In the mean time V is again filled with steam. The communication between T and the boiler is now closed, and that between T′ and the boiler is opened, and the condensing pipe removed from V′ and brought to play on V. While the steam from the boiler forces the water in V′ through B′ into the forcepipe F, a vacuum is being produced in V into which water is raised by the atmospheric pressure at L.

Thus each of the vessels V V′ is alternately filled from S and the water thence forced into F. The same steam which forces the water from the vessels into F, having done its duty, is condensed, and brings up the water from S by giving effect to the atmospheric pressure.

During this process, two alternate motions or adjustments must be constantly made; the communication between T and the boiler must be opened, and that between T′ and the boiler closed, which is done by one motion of the regulator. The condensing pipe at the same time must be brought from V to play on V′ which is done by the lever placed upon it. Again the communication between T′ and the boiler is to be opened, and that between T and the boiler closed; this is done by moving back the regulator. The condensing pipe is brought from V′ to V by moving back the other lever, and so on alternately.

(27.) Such are the construction and operation of the steam-engine, contrived by Captain Savery in the year 1698, and which is the first instance in which we have satisfactory evidence of the use of steam, as a moving power, on any scale worthy of mention. For the clearness and convenience of description, I have made some slight and otherwise unimportant changes in the position of the parts. * A perspective view of this engine is presented in fig. 9. The different parts already described will easily be recognized, being marked with the same letters as in fig. 6, 7.

(28.) Savery's share in the invention of the steam-engine is easily assigned. It will be seen in a future lecture that the motion, in modern steam-engines, is produced by placing a piston in a cylinder, and producing a vacuum on one side of the piston by the condensation of steam, while the elastic pressure of steam is introduced at the other side. Thus, while the pressure on the one side of the piston is effected by the direct mechanical agency of steam, discovered by Lord Worcester, that pressure is rendered efficacious by the vacuum generated on the other side by the method of condensing the steam, discovered by Captain Savery. Thus, the whole honor of the discovery of those properties of steam, on which its power as a first mover depends, is to be equally shared

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* In the diagrams used for explaining the principles and operation of machines, I have found it contribute much to the clearness of the description to adopt an arrangement of parts somewhat different from that of the real machine. When once the nature and principles on which the machine acts are well understood. The reader will find no difficulty in transferring every part to its proper place, which is represented in the perspective drawings.

between these two distinguished individuals. This, however, is the extent of their claims. All the beautiful contrivances by which this vast power is applied, regulated and economised, are the result of the ingenuity of their successors, and the engine suggested by Worcester and that constructed by Savery will be found to have scarcely any thing in common with those of the present day, except their *first mover.*

LECTURE III.

Defects of Savery's Engine — Newcomen and Cawley — The Atmospheric Engine — Condensation by jet discovered — Operation of the Engine — Humphrey Potter's Invention to make the Engine work itself.

(29.) In order duly to appreciate the value of improvements, it is necessary first to perceive the defects which these improvements are designed to remove. Savery's steam-engine, described in the last lecture, considering how little was known of the value and properties of steam, and how low the general standard of mechanical knowledge was in his day, is certainly highly creditable to his genius. Nevertheless it had very considerable defects, and was finally found to be inefficient for the most important purposes to which he proposed applying it.

At the time of this invention, the mines in England had greatly increased in depth, and the process of draining them had become both expensive and difficult; so much so, that it was found in many instances that their produce did not cover the cost of working them. The drainage of these mines was the great object Savery proposed to effect by his steam-engine.

It has been already stated, that the pressure of the atmosphere amounts to about 15lbs. (4) on every square inch. Now, a column of water, whose base is one square inch, and whose height is 34 feet, weighs about 15lbs. If we suppose that a perfect vacuum were produced in the steam-vessels v v′ (fig. 8.) by condensation, the atmospheric pressure on L would fail to force up the water, if the height of the top of these vessels exceeded 34 feet. It is plain, therefore, from this reasoning, that the engine cannot be more than 34 feet above the water which it is intended to elevate. But in fact it cannot be even so much; for the vacuum produced in the steam-vessels v v′ is never perfect. Water, when not submitted to the pressure of the atmosphere, will vaporize at a very low temperature (17); and it was found, that a vapour possessing a considerable elasticity would, notwithstanding the condensation, remain in the vessels v v′ and the pipe s, and would oppose the ascent of the water. In consequence of this, it was found that the engine could never be placed with practical advantage at a greater height than 26 feet above the level of the water to be raised.

(30). When the water is elevated to the engine, and the steam-vessels filled, if steam be introduced above the water in v, it must first balance the atmospheric pressure, before it can force the water through the valve B. Here, then, is a mechanical pressure of 15lbs. per square inch expended, without any water raised by it. If steam of twice that elastic force be used, it will elevate a column in F of 34 feet in height; and if steam of treble the force be used, it will raise a column of 68 feet high, which, added to 26 feet raised by the atmosphere, gives a total lift of 94 feet.

In effecting this, steam of a pressure equal to three times that of the atmosphere, acts on the inner surface of the vessels v v′. One third of this bursting pressure is balanced by the pressure of the atmosphere on the external surface of the vessels; but an effective pressure of 30lbs. per square inch still remains, tending to burst the vessels. It was found, that the apparatus could not be constructed to bear more than this with safety; and, therefore, in practice the lift of such an engine was limited to about 90 perpendicular feet. In order to raise the water from bottom of the mine by these engines, therefore, it was necessary to place one at every 90 feet of the depth; so that the water raised by one through the first 90 feet, should be received in a reservoir, from which it was to be elevated the next 90 feet by another, and so on.

Besides this, it was found sufficient strength could not be given to those engines, if constructed upon a large scale. They were, therefore, necessarily very limited in their dimensions, and were incapable of raising the water with sufficient speed. Hence arose a necessity for several engines at each level, which greatly enhanced the expense.

(31.) These, however, were not the only defects of Savery's engines. The consumption of fuel was enormous, the proportion of heat wasted being much more than what was used in either forcing up the water, or producing a *vacuum*. This will be very easily understood by attending to the process of working the engine described in the last lecture.

When the steam is first introduced from the boiler into the steam-vessels V V′, preparatory to the formation of a vacuum, it is necessary that it should heat these vessels up to the temperature of the steam itself, viz. 212°; for until then the steam will be condensed the moment it enters the vessel by the cool surface. All this heat, therefore, spent in raising the temperature of the steam-vessels is wanted. Again, when the water has ascended and filled the vessels V V′, and steam is introduced to force this water through B B′ into F, it is immediately condensed by the cold surface in V V′, and does not begin to act until a quantity of hot water, formed by condensed steam, is collected on the surface of 'the cold water which fills the vessel V V′. Hence another source of the waste of heat. arises

When the steam begins to act upon the surface of the water in V V′, and to force it down, the cold surface of the vessel is gradually exposed to the steam, and must be heated while the steam continues its action; and when the water has been forced out of the vessel, the vessel itself has been heated to the temperature of the steam which fills it, all which heat is dissipated by the subsequent process of condensation. It must thus be evident that the steam used in forcing up the water in F, and in producing a vacuum, bears a very small proportion indeed to what is consumed in heating the apparatus after every condensation.

There is also another circumstance which increases the consumption of fuel. When the water is to be forced through B, not only against the atmospheric pressure, but against a column of 68 feet of water, steam is required of a pressure of 45lbs. on the square inch. Consequently the water in the boiler must be boiling under this pressure. That this should take place, it is necessary that the water should be raised to a temperature considerably above 212° (17), even so high as 267°; and thus an increased heat must be given to the boiler. Independently of the other defects, this intense heat weakened and gradually destroyed the apparatus.

Besides the drainage of mines, Savery proposed to apply his steam-engine to a variety of other purposes; such as supplying cities with water, forming ornamental water-works in pleasure grounds, turning mills, &c.

Savery was the first who suggested the method of expressing the power of an engine with reference to that of horses. In this comparison, however, he supposed each horse to work but 8 hours a day, while the engine works for 24 hours. This method of expressing the power of steam-engines will be explained hereafter.

(32.) The failure of the engines proposed by Captain Savery in the great work of drainage, from the causes which have been just mentioned; and the increasing necessity for effecting this, arising from the circumstance of the large properties which became every year unproductive by it, stimulated the ingenuity of mechanics to contrive some means of rendering those powers of steam exhibited in Savery's engine practically available. Among others, NEWCOMEN and CAWLEY, two tradesmen of the town of Dartmouth, turned their attention to this enquiry.

Newcomen appears to have resumed the old method of raising the water from the mines by ordinary pumps, but conceived the idea of working these pumps by some moving power less expensive than that of horses. The means whereby he proposed effecting this, was by connecting the end of the pump-rod D (fig. 10.), by a chain, with the arch head A of a working beam A B, playing on an axis C. The other arch head B of this beam was connected by a chain with the rod E of a solid piston P, which moved air-tight in a cylinder F. If a vacuum be created beneath the piston P, the atmospheric pressure acting upon it will press it down with a force of 15lbs. per square inch; and the end A of the beam being thus raised, the pump-rod D will be drawn up. If a pressure equivalent to the atmosphere be then introduced below the piston, so as to neutralize the downward pressure, the piston will be in a state of indifference as to rising or falling; and if in this case the rod D be made heavier than the piston, and its rod so as to overcome the friction, &c. it will descend, and elevate the piston again to the top of the cylinder. The vacuum being again produced, another descent of the piston, and consequent elevation of the pump-rod, will take place; and so the process may be continued.

Such was Newcomen's first conception of the *atmospheric engine;* and the contrivance had much, even at the first view, to recommend it. The power of such a machine would depend entirely on the magnitude of the piston; and being independent of an highly elastic steam, would not expose the materials to the destructive heat which was necessary for working Savery's engine. Supposing a perfect vacuum to be produced under the piston in the cylinder, an effective downward pressure would be obtained, amounting to 15 times as many pounds as there are square inches in the section of the piston.* Thus, if the base of the piston were 100 square inches, a pressure equal to 1500lbs. would be obtained.

(33.) In order to accomplish this design, two things were necessary: 1°. To make a speedy and effectual vacuum below the piston in the descent; and 2°. to contrive a counterpoise for the atmosphere in the ascent.

The condensing principle of Savery immediately presented itself as the most effectual means of accomplishing the former; and the elastic force of the steam introduced to be condensed, an obvious method of effecting the latter. Nothing now remained to carry the design into execution, but the contrivance of mechanism for the alternate introduction and condensation of the steam ; and Newcomen and Cawley were accordingly granted a patent in 1707, in which Savery was united, in consequence of his principle of condensation being vitally necessary to the projected machine. We shall now describe the *atmospheric engine,* as first constructed by Newcomen:

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* As the calculation of the power of an engine depends on the number of square inches in the section of the piston, it may be useful to give a rule for computing the number of square inches in a circle. The following rule will always give the dimensions with sufficient accuracy: *Multiply the number of inches in the diameter by itself; divide the product by* 14, *and multiply the quotient thus obtained by* 11, *and the result will be the number of square inches in the circle.* Thus if there be 12 inches in the diameter, this multiplied by itself gives 144, which divided by 14 gives 10$\frac{2}{7}$, which multiplied by 11 gives 115, neglecting fractions There are, therefore, 115 square inches in a circle whose diameter is 12 inches.

The boiler K is placed over a furnace I, the flue of which winds round it, so as to communicate heat to every part of the bottom of it. In the top, which is hemispherical, two gauge-pipes G G′ are placed, as in Savery's engine, and a *puppet valve* V, which opens outward, and is loaded at one pound per square inch ; so that when the steam produced in the boiler exceeds the pressure of the atmosphere by more than one pound on the square inch, the valve V is lifted, and the steam escapes through it, and continues to escape until its pressure is sufficiently diminished, when the valve V again falls into its seat.

The great steam-tube is represented at S, which conducts steam from the boiler to the cylinder, and a feeding pipe T furnished with a cock, which is opened and closed at pleasure, proceeds from a cistern L to the boiler. By this pipe the boiler may be replenished from the cistern, when the gauge cock G′ indicates that the level has fallen below it. The cistern L is supplied with hot water by means which we shall presently explain.

(34.) To understand the mechanism necessary to work the piston, let us consider how the supply and condensation of steam must be regulated. When the piston has been forced to the bottom of the cylinder by the atmospheric pressure acting against a vacuum, in order to balance that pressure, and enable it to be drawn up by the weight of the pump-rod, it is necessary to introduce steam from the boiler. For this purpose, therefore, the steam-pipe S enters the bottom of the cylinder. The pressure of the steam being thus introduced, the piston ascends; and when it has reached the top of the cylinder, the space below it is completely filled with steam. It then becomes necessary to condense this steam, in order to produce a vacuum. To accomplish this the further supply of steam must be cut off, which is done by a sliding plate R,* similar to the *regulator* in Savery's engine, and which is moved over the aperture in the bottom of the cylinder by means of a lever as already described. The supply of steam from the boiler being thus suspended, the affusion of cold water on the external surface of the cylinder becomes necessary to condense the steam within it. This was done by enclosing the cylinder within another, leaving a space between them.† Into this space cold water is allowed to flow from a cock M placed over it, which is supplied by a pipe from the cistern N. This cistern is supplied with water by a pump O, which is worked by the engine itself, from the beam above it.

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* This is represented as a cock, in the diagram.

† The external cylinder is not represented in the diagram.

The cold water supplied from M, having filled the interstice between the two cylinders, abstracts the heat from the inner one; and condensing the steam, produces a vacuum, into which the piston is immediately forced by the atmospheric pressure. Preparatory the next descent, the water which thus fills the space between the cylinders, and which is warmed by the heat it has abstracted from the steam, must be discharged, in order to give room for a fresh supply of cold water from M. An aperture, furnished with a cock, is accordingly provided in the bottom of the cylinder, through which the water is discharged into the cistern L; and being warm, is better adapted for the supply of the boiler through T, as already mentioned.

The regulator R being now again opened, steam is admitted below the piston, which, as before, ascends, and the descent is again accomplished by condensation; and so the process may be continued.

Upon cooling the inner cylinder, the condensed steam, being reduced to water, will collect in the bottom, and resist the descent of the piston. It is, therefore, necessary to provide an exit for it, which is done by a valve opening *outwards* into a tube which leads to the feeding cistern L, into which the condensed steam is driven.

That the piston should continue to be air-tight, it was necessary to keep a constant supply of water over it; this was done by a cock similar to M, which allowed water to flow from the pipe M on the piston.

(35.) Soon after the first construction of these engines, an accidental circumstance suggested to Newcomen, a much better method of condensation than the affusion of cold water on the external surface of the cylinder. An engine was observed to work several strokes with unusual rapidity, and without the regular supply of the condensing water. Upon examining the piston, a hole was found in it through which the water, which was poured on to keep it air-tight, flowed, and instantly condensed the steam under it.

On this suggestion Newcomen abandoned the external cylinder, and introduced a pipe H furnished with a cock Q into the bottom of the cylinder, so that, on turning the cock the pressure of the water, in the pipe H from the level of the water in the cistern N, would force the water to rise as a jet into the cylinder, and would instantly condense the steam. This method of condensing by a jet formed a very important improvement in the engine, and is the method still used.

(36.) Having taken a general view of the parts of the atmospheric engine, let us now consider more particularly its operation.

When the engine is not working the weight of the pump-rod D draws down the beam A, and draws the piston to the top of the cylinder where it rests. Let us suppose all the cocks and valves closed, and the boiler filled to the proper depth. The fire being lighted beneath it, the water is boiled until the steam acquires sufficient force to lift the valve V.

When this takes place the engine may be started. For this purpose the regulating valve R is opened. The steam rushes in and is first condensed by the cold cylinder. After a short time the cylinder acquires the temperature of the steam, which then ceases to be condensed, and mixes with the air which filled the cylinder. The steam and heated air, having a greater force than the atmospheric pressure, will open a valve placed at the end X of a small tube in the bottom of the cylinder, and which opens outwards. From this (which is called the *blowing valve**) the steam and air rush in a constant stream until all the air has been expelled, and the cylinder is filled with the pure vapor of water. This process is called *blowing* the engine preparatory to starting it.

When it is about to be started, the engine-man closes the regulator R, and thereby suspends the supply of steam from the boiler. At the same time he opens the *condensing valve* Q ;† and thereby throws up a jet of cold water into the cylinder. This immediately condenses the steam contained in the cylinder and produces the vacuum. (The atmosphere cannot enter the *blowing* valve because it opens *outwards*, so that no air can enter to vitiate the vacuum.) The atmospheric pressure above the piston now takes effect, and forces it down in the cylinder. The descent being completed, the engine-man closes the condensing valve Q, and opens the regulator R. By this means he stops the play of the jet within the cylinder, and admits the steam from the boiler. The first effect of the steam is to expel the condensing water and condensed steam which are collected in the bottom of the cylinder thro' a tube Y containing a valve which opens *outwards* (called the *eduction valve,*) and which leads to the hot cistern L, into which this water is therefore discharged.

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* Also called the *snifting* valve from the peculiar noise made by the air, and steam escaping from it

† Also called the *injection valve*.

When the steam admitted through R ceases to be condensed, it balances the atmospheric pressure above the piston, and thus permits it to be drawn to the top of the cylinder by the weight of the rod D. This ascent of the piston is also assisted by the circumstance of the steam being somewhat stronger than the atmosphere.

When the piston has reached the top, the regulating valve R is closed, and the condensing valve Q opened, and another descent produced as before, and so the process is continued.

The manipulation necessary in working this engine was, therefore, the alternate opening and closing of two valves, the regulating and condensing valves. When the piston reached the top of the cylinder, the former was to be closed, and the latter opened, and, on reaching the bottom, the former was to be opened, and the latter closed.

(37.) From the imperfect attention which even an assiduous attendant could give to the management of these valves, the performance of the engines was very irregular, and the waste of fuel very great, until a boy named *Humphrey Potter* contrived means of making the engine work its own valves. This contrivance, although made with no other design than the indulgence of an idle disposition, nevertheless constituted a most important step in the progressive improvement of the steam-engine, for by its means, not only the irregularity arising from the negligence of attendants was avoided, but the operation of the engine was doubled; so that one half of the fuel was saved.

Potter attached strings to the levers which worked the valves, and carrying these strings to the working beam, fastened them upon it in such a manner that as the beam ascended and descended, it pulled the strings so as to open and close the proper valves with the most perfect regularity and certainty. This contrivance was afterwards much improved by an engineer named *Beighton,* who attached to the working beam a straight beam called a *plug frame,* carrying pins which, in the ascent and descent of the beam, struck the levers attached to the valves, and opened and closed them exactly at the proper moment.

The engine thus improved required no other attendance except to feed the boiler occasionally by the cock T, and to attend the furnace.

LECTURE IV.

Advantages of the Atmospheric Engine over that of Captain Savery. It contained no new Principle—Papin's Engine—Unfounded Claims of the French for the Invention of the Steam-Engine—James Watt—Particulars of his Life. His first Conceptions of the Means of economising Heat. Principle of his projected Improvements.

(38.) CONSIDERED practically, the engine described in the last lecture possessed considerable advantages over that of Savery; and even at the present day this machine is not unfrequently used in districts where fuel is very abundant and cheap, the first cost being considerably less than that of a modern engine. The low pressure of the steam necessary to work it, rendered the use of the atmospheric engine perfectly safe; there being only a bursting pressure of about 1 lb. per inch, while in Savery's there was a bursting pressure amounting to 30lbs. The temperature of the steam not exceeding 216°, did not weaken or destroy the materials; while Savery's engines required steam raised from water at 267°, which in a short time rendered the engine unable to sustain the pressure.

The power of Savery's engines was also very limited, both as to the quantity of water raised, and the height to which it was elevated. (29) On the other hand, the atmospheric engine had no other limit than the dimensions of the piston. In estimating the power of these engines, however, we cannot allow the full atmospheric pressure as an effective force. The condensing water being mixed with the condensed steam, forms a quantity of hot water in the bottom of the cylinder, which, not being submitted to the atmospheric pressure (17), produces a vapour which resists the descent of the piston. In practice we find that an allowance of at least 3lbs. per square inch should be made for the resistance of this vapour, and 1lb. per square inch for friction, &c.; so that the effective force will be found by subtracting these 4lbs. per square inch from the atmospheric pressure; which, if estimated at 15lbs. leaves an effective working power of about 11lbs. per square inch. This, however, is rather above what is commonly obtained.

Another advantage which this engine has over those of Savery, is the facility with which it might be applied to drive machinery by means of the working beam.

(39.) On the score of invention, Newcomen does not appear to have much claim. The agency of the atmospheric pressure was long known; the formation of a vacuum by the condensation of steam was Savery's discovery; the elastic force of steam used to balance the atmosphere in the ascent, was the discovery of lord Worcester; the construction of the boiler, gauge-pipes, regulator, &c. were similar to those in Savery's engines. The idea of working a piston in a cylinder by the atmospheric pressure, by forming a vacuum below it, was suggested by Otto Guericke, an ingenious German philosopher, and the inventor of the air-pump. The use of a working-beam could not have been unknown. Nevertheless, very considerable credit must be acknowledged to be due to Newcomen for the judicious combination of all these scattered principles, so as to form the atmospheric engine.

(40.) The patent of Newcomen was granted in 1705; and in 1707, PAPIN, a native of France, and professor of mathematics at *Marpurg*, published a work entitled, "A New Method of raising Water by Fire," in which a steam-engine is described, which would scarcely merit notice here, were it not that it forms the ground on which the French claim the invention of the steam-engine. The publication of Papin's work was nine years after Savery's patent, with which he acknowledges himself acquainted, and two years after Newcomen's. The following is a description of Papin's steam-engine:

An oval boiler, A (fig. 11.), is filled to about two-thirds of its entire capacity with water, through a valve B in the top, which opens upwards, and is kept down by a lever carrying a sliding weight. The pressure on the valve is regulated by moving the weight to or from B, like the common steelyard. This boiler communicates with a cylinder C, by a syphon tube furnished with a stopcock at D. The cylinder C has a valve F in the top, closed by a lever and weight similar to B, and a tube with a stopcock G opening into the atmosphere. In this cylinder is placed a hollow copper piston H, which moves freely in it, and floats upon the water. Another tube forms a communication between the bottom of this cylinder and the bottom of a close cylindrical vessel I, called the *air-vessel.* In this tube is a valve at K, opening *upwards,* also a pipe terminated in a funnel, and furnished with a valve L, which opens *downwards.* From the lower part of the air-vessel a tube proceeds, furnished also with a stopcock M, and which is continued to whatever height the water is to be raised.

Water being poured into the funnel, passes through the valve L, which opens downwards, and filling the tube, ascends into the cylinder C, carrying the floating piston H on its surface, and maintains the same level in C which it has in the funnel. In this manner the cylinder C may be filled to the level of the top of the funnel. In this process, the cock G should be left open to allow the air in the cylinder to escape as the water rises

Let us now suppose that, a fire being placed beneath the boiler, steam is being produced. On opening the cock D, and closing G, the steam, flowing through the syphon tube into the top of the cylinder, presses down the floating piston, and forces the water through the lower tube. The passage at L being stopped, since L opens *downwards,* the water forces open the valve K, and passes into the air-vessel I. When the piston H has been forced to the bottom of the cylinder, the cock D is closed, and G is opened, and the steam allowed to escape into the atmosphere. The cylinder is then replenished from the funnel as before; and the cock G being closed, and D opened, the process is repeated, and more water forced into the air-vessel I.

By continuing this process, water is forced into the air-vessel; and the air which originally filled that vessel is compressed into the space above the water; and its elastic force increases exactly in the same proportion as its bulk is diminished. (6) Now, suppose that half of the vessel I has been filled by the water which is forced in, the air above the water being reduced to half its bulk, has acquired twice the elastic force, and therefore presses on the surface of the water with twice the pressure of the atmosphere. Again, if two thirds of the air-vessel be filled with water, the air is compressed into one third of its bulk, and presses on the surface of the water with three times the pressure of the atmosphere, and so on.

Now if the cock M be opened, the pressure of the condensed air will force the water up in the tube N, and it will continue to rise until the column balances the pressure of the condensed air. If, when the water is suspended in the tube, and the cock M open, the vessel I is half filled, the height of the column in N will be 34 feet; because 34 feet of water has a pressure equal to the atmosphere; and this added to the atmospheric pressure on it, gives a total pressure equal to twice that of the atmosphere, which balances the pressure of the air in I reduced to half its bulk. If two thirds of I be filled with water, a column of 68 feet will be supported in N; for such a column, united with the atmospheric pressure on it, gives a total pressure equal to three times that of the atmosphere, which balances the air in I, compressed into one third of its original bulk.

(41.) By omitting the principle of condensation, this machine loses 26 feet in the perpendicular lift.(29) But, indeed, in every point of view, it is inferior to the engines of Savery and Newcomen: and the date of its first publication puts an end to all question respecting the right of Papin to any share in the invention of the steam-engine. Even had the publication of Papin's contrivance preceded that of Savery, he would still have been entitled to no share in the invention—the principle which he uses being only the elastic force of steam, which had long before been suggested by Lord Worcester.

(42.) From the construction of the atmospheric engine by Newcomen, in 1705, for about half a century, no very important step had been made in the improvement of the steam-engine. During this time the celebrated SMEATON had given much of his attention to the details of the atmospheric engine, and brought that machine to as high a state of perfection as its principle seemed to admit, and as it has ever since reached.

In the year 1763, JAMES WATT, a name illustrious in the history of mechanical science, commenced his experiments on steam. He was born at Greenock, in the year 1736; and at the age of 16 was apprenticed to a mathematical instrument maker, with whom he spent four years. At the age of 20 he placed himself under a regular mathematical instrument maker in London. After a short time, finding his health declining, he returned to Scotland, and commenced business on his own account at Glasgow. In 1757 he was appointed mathematical instrument maker to the university of Glasgow, where he resided and carried on his business.

This circumstance produced an acquaintance between him and the celebrated Dr. Robison, then a student in Glasgow, who directed Watt's attention to the steam-engine. In his first experiments he used steam of a high pressure; but found it attended with so much danger of bursting the boiler, and difficulty of keeping the joints tight, and other objections, that he relinquished the enquiry at that time.

(43.) In the winter of 1763, Watt was employed to repair the model of an atmospheric engine, belonging to the natural philosophy class in the university, a circumstance which again turned his attention to the subject of the steam-engine. He found the consumption of steam in working this model so great, that he concluded that the quantity wasted must have had a very large proportion to that used in working the piston. His first conclusion was, that the material of the cylinder (brass) was too good a conductor of heat, and that much was thereby lost. He made some experiments, accordingly, with wooden cylinders soaked in linseed oil, which, however, he soon laid aside. Further consideration convinced him that a prodigious waste of steam was essential to the very principle of the atmospheric engine. This will be easily understood.

When the steam has filled the cylinder so as to balance the atmospheric pressure on the piston, the cylinder must have the same temperature as the steam itself. Now, on introducing the condensing jet, the steam mixed with this water forms a mass of hot water in the bottom of the cylinder. This water, not being under the atmospheric pressure, boils at very low temperatures, and produces a vapour which resists the descent of the piston.

The heat of the cylinder itself assists this process; so that in order to produce a tolerably perfect vacuum under the piston, it was found necessary to introduce a quantity of condensing water, sufficient to reduce the temperature of the water in the cylinder lower than 100°, and consequently to cool the cylinder itself to that temperature. Under these circumstances, the descent of the piston was found to suffer very little resistance from any vapour within the cylinder; but then on the subsequent ascent, an immense waste of steam ensued. For the steam on being admitted under the piston, was immediately condensed by the cold cylinder and water of condensation, and this continued until the cylinder became again heated up to 212°, to which point the whole cylinder should be heated before the ascent could be completed. Here, then, was an obvious and an extensive source of the waste of heat. At every descent of the piston, the cylinder should be cooled to below 100°; and at every ascent it should be again heated to 212°. It, therefore, became a question whether the force gained by the increased perfection of the vacuum, was adequate to the waste of fuel in producing the vacuum; and it was found, on the whole, more profitable not to cool the cylinder to so low a temperature, and consequently to work with a very imperfect vacuum, and a diminished power.

Watt, therefore, found the engine involved in this dilemma: either much or little condensation-water was to be used. If much were used, the vacuum would be perfect; but then the cylinder would be cooled, and would entail an extensive waste of fuel in heating it. If little were used, a vapour would remain, which would resist the descent of the piston, and rob the atmosphere of a part of its power. The great problem then pressed itself on his attention, *to condense the steam without cooling the cylinder.*

From the small quantity of water in the form of steam which filled the cylinder, and the large quantity of injected water to which this communicated heat, Watt was led to enquire what proportion the bulk of water in the liquid state bore to its bulk in the vaporous state; and also what proportion subsisted between the heat which it contained in these two states. He found by experiment that a cubic inch of water formed a cubic foot of steam; and that the cubic foot of steam contained as much heat as would raise a cubic inch of water to about 800°. (19) This gave him some surprise, as the thermometer indicated the same temperature, 212°, for both the steam and the water from which it was raised. What then became of all the additional heat which was contained in the steam, and not indicated by the thermometer? Watt concluded that this heat must be in some way engaged in maintaining the water in its new form.

Struck with the singularity of this circumstance, he communicated it to Dr. Black, who then explained to Watt his doctrine of *latent heat*, which he had been teaching for a short time before that, but of which Watt had not previously heard; and thus, says Watt, "I stumbled upon one of the material facts on which that theory is founded."

(44.) Watt now gave his whole mind to the consideration of a method of "condensing the steam without cooling the cylinder." The idea occurred to him of providing a vessel separate from the cylinder, in which a constant vacuum might be kept up. If a communication could be opened between the cylinder and this vessel, the steam, by its expansive property, would rush from the cylinder to this vessel, where, being exposed to cold, it would be immediately condensed, the cylinder meanwhile being sustained at the temperature of 212°.

This happy conception formed the first step of that brilliant career, which has immortalized the name of Watt, and which has spread his fame to the very skirts of civilization. He states, that the moment the notion of "separate condensation" struck him, all the other details of his improved engine followed in rapid and immediate succession, so that in the course of a day his invention was so complete, that he proceeded to submit it to experiment.

His first notion was, as we have stated, to provide a separate vessel, called a *condenser*, having a pipe or tube communicating with the cylinder. This condenser he proposed to keep cold by being immersed in a cistern of cold water, and by providing a jet of cold water to play within it. When the communication with the cylinder is opened, the steam, rushing into the condenser, is immediately condensed by the jet and the cold surface. But here a difficulty presented itself, viz. how to dispose of the condensing-water, and condensed steam, which would collect in the bottom of the condenser? Besides this, a certain quantity of air would inevitably enter combined with the condensing water, which, accumulating, would collect in the cylinder and resist the descent of the piston. To remedy this he proposed *to form a communication between the bottom of the condenser and a pump which he called the* AIR PUMP, *so that the water and air, or other fluids, which might be collected in the condenser, would thus be drawn off;* and it was easy to see how this pump could be worked by the machine itself. This constituted the second great step in the invention.

It had been found necessary, that the piston might move air-tight in the cylinder, to keep a quantity of water supplied above it. In the present case, any of this water which might escape through the piston, or between it and the cylinder, would boil, the cylinder being proposed to be kept at 212°; and would thus, by the steam it would produce, vitiate the vacuum. To avoid this inconvenience, Watt proposed to lubricate the piston, and keep it air-tight, by employing melted wax and tallow.

Another inconvenience was still to be removed. On the descent of the piston, the air which entered the cylinder would lower its temperature; so that, upon the next ascent, some of the steam which entered it would be condensed, and hence would arise a source of waste. To remove this difficulty, Watt proposed to close the top of the cylinder altogether, by an air tight and steam-tight cover, allowing the piston-rod to play through a hole furnished with a stuffing-box, and *to press down the piston by steam instead of the atmosphere.*

This was the third step in this great invention, and one which totally changed the character of the machine. It now became really a *steam-engine* in every sense; for the pressure above the piston was the elastic force of steam, and the vacuum below it was produced by the condensation of steam; so that steam was used both directly and indirectly as a moving power; whereas, in the atmospheric engine, the indirect force of steam only was used, being adopted merely as an easy method of producing a vacuum.

The last difficulty respecting the economy of heat which remained to be removed, was the circumstance of the cylinder being liable to be cooled on the external surface by the atmosphere. To obviate this, he first proposed casing the cylinder in wood, as being a substance which conducted heat slowly. He subsequently, however, adopted a different method, and enclosed one cylinder within another, leaving a space between them, which he kept constantly supplied with steam. Thus the inner cylinder was kept continually at the temperature of the steam which surrounded it. The outer cylinder is called the *jacket.* *

(45.) Watt computed that in the atmospheric engine three times as much heat was wasted in heating the cylinder, &c. as was spent in useful effect. And, as by the improvements proposed by him nearly all waste was removed, he contemplated, and afterwards actually effected, a saving of three-fourths of the fuel.

The honour due to Watt for his discoveries is enhanced by the difficulties under which he laboured from contracted circumstances at the time he made them. He relates, that when he was endeavouring to determine the heat consumed in the production of steam, his means did not permit him to use an efficient and proper apparatus, which would have been attended with expense; and it was by experiments made with apothecaries' phials, that he discovered the property already mentioned, and which was one of the facts on which the doctrine of latent heat was founded.

A large share of the merit of Watt's discoveries has, by some writers, been attributed to Dr. Black, to whose instructions on the subject of latent heat, &c. it is said that Watt owed the knowledge of those facts which led to his improvements. Such, however, was not the case; and the mistake arose chiefly from some passages respecting Watt in the works of Dr. Robinson, in one of which he states him to have been a *pupil* and intimate friend of Dr. Black; and that he attended two courses of his lectures at college in Glasgow. Such, however, was not the case; for, "Unfortunately for me," says Watt in a letter to Dr. Brewster, "the necessary avocations of my business prevented me from attending his or any other lectures at college. In further noticing Dr. Black's opinion, that his fortunate observation of what happens in the formation and condensation of elastic vapour 'has contributed in no inconsiderable degree to the public good, by suggesting to my friend Mr. Watt of Birmingham, then of Glasgow, his improvements on the steam-engine,' it is very painful for me to controvert any opinion or assertion of my revered friend; yet, in the present case I find it necessary to say, that he appears to me to have fallen into an error. These improvements proceeded upon the established fact, that steam was condensed by the contact of cold bodies, and the later known one, that water boiled at heats below 100°, and consequently that a vacuum could not be obtained unless the cylinder and its contents were cooled every stroke below that heat."

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* It is a remarkable circumstance, that Watt used the same means for keeping the cylinder hot, as Newcomen used in his earlier engines to cool it. (34)

LECTURE V.

WATT's single-acting Steam-Engine — Expansive principle applied — Failure of Roebuck, and partnership with Bolton — Patent extended to 1800 — Counter — Difficulties in getting the Engines into use.

(46.) THE first machine in which Watt realized the conceptions which we mentioned in the last lecture, is that which was afterwards called his *Single-acting Steam-Engine.* We shall now describe the working apparatus in this machine.

The cylinder is represented at C—(fig. 12) in which the piston P moves steam-tight. It is closed at the top, and the piston rod being very accurately turned, runs in a steam-tight collar B furnished with a stuffing-box, and constantly supplied with melted tallow or wax. Through a funnel in the top of the cylinder, melted grease flows upon the piston so as to maintain it steam-tight. Two boxes A A, containing the valves for admitting and withdrawing the steam, connected by a tube of communication T, are attached to the cylinder; the action of these valves will be presently described. Below the cylinder, placed in a cistern of cold water, is a close cylindrical vessel D, called the condenser, communicating with the cylinder by a tube T′, leading to the lower valve box A. In the side of this condenser is inserted a tube, the inner end of which is pierced with holes like the rose of a watering-pot, and a cock E in the cold cistern is placed on the outside, through which, when open, the water passing, rises in a jet on the inside.

The tube S which conducts steam from the boiler, enters the top of the upper valve box at F. Immediately under it is placed a valve G which is opened and closed by a lever or rod G′. This valve, when open, admits steam to the top of the piston, and also to the tube T, which communicates between the two valve boxes, and when closed, suspends the admission of steam. There are two valves in the lower box, one H in the top worked by the lever H′, and one I in the bottom worked by the lever I′. The valve H when open, admits steam to pass from the cylinder *above* the piston, by the tube T, to the cylinder *below* the piston, the valve I being supposed in this case to be closed. This valve I when open (the valve H being closed) admits steam to pass from below the cylinder through T′ to the condenser. This steam entering the condenser, meets the jet, admitted to play by the valve E, and is condensed.

The valve G is called the *upper steam-valve;* H, the *lower steam-valve;* I, the *exhausting valve;* and E, the *condensing valve.* Let us now consider how these valves must be worked in order to produce the alternate ascent and descent of the piston.

It is in the first place necessary, that all the air which fills the cylinder, tubes, and condenser, should be expelled. To accomplish this, it is only necessary to open at once the valves G, H, and I. The steam then rushing from F through the valve G will pass into the upper part of the cylinder, and through the tube T and the valve H into the lower part, and also through the valve I into the condenser. After the steam ceases to be condensed by the cold of the apparatus, it will rush out mixed with air through the valve M which opens outwards; and this will continue until all the air has been expelled, and the apparatus filled with pure steam. Then suppose all the valves again closed. The cylinder both above and below the piston is filled with steam; and the steam which filled the condenser being cooled by the cold surface, a vacuum has been produced in that vessel.

The apparatus being in this state, let the upper steam valve G, the exhausting valve I, and the condensing valve E be opened. Steam will thus be admitted through G to press on the top of the piston; and this steam will be prevented from circulating to the lower part of the cylinder by the lower steam-valve H being closed. Also the steam which filled the cylinder below the piston rushes through the open exhausting valve I to the condenser where it meets the jet allowed to play by the open condensing valve E. It is thus instantly condensed, and a vacuum is left in the cylinder below the piston. Into this vacuum the piston is pressed without resistance by the steam which is admitted through G. When the piston has thus been forced to the bottom of the cylinder, let the three valves G, I, and E, which were before opened, be closed, and let the lower steam-valve H be opened. The effects of this change are easily perceived. By closing the upper steam-valve G, the further admission of steam to the apparatus is stopped. By closing the exhausting valve I, all transmission of steam from the cylinder to the condenser is stopped. Thus the steam which is *in* the cylinder, valve-boxes, and tubes is shut up in them, and no more admitted, nor any allowed to escape. By closing the condensing valve E, the play of the jet in the condenser is suspended.

Previously to opening the valve H, the steam contained in the apparatus was confined to the part of the cylinder *above* the piston and the tube T and valve box A. But on opening this valve, the steam is allowed to circulate above and below the piston; and in fact through every part included between the upper steam valve G, and the exhausting valve I. The same steam circulating on both sides, the piston is thus equally pressed upwards and downwards.

In this case there is no force tending to retain the piston at the bottom of the cylinder except its own weight. Its ascent is produced in the same manner as the ascent of the piston in the atmospheric engine. The piston-rod is connected by chains G, to the arch-head of the beam, and the weight of the pump-rod R or any other counterpoise acting on the chains suspended from the other arch-head draws the piston to the top of the cylinder.

When the piston has arrived at the top of the cylinder, suppose the three valves G, I, and E to be again opened, and H closed. Steam passes from the steam-pipe F through the upper steam valve G to the top of the piston and at the same time the steam which filled the cylinder below the piston is drawn off through the open exhausting valve I into the condenser where it is condensed by the jet allowed to play by the open condensing valve E. The pressure of the steam above the piston then forces it without resistance into the vacuum below it, and so the process is continued.

It should be remembered, that of the four valves necessary to work the piston, three are to be opened the moment the piston reaches the top of the cylinder, and the fourth is to be closed; and on the piston arriving at the bottom of the cylinder, these three are to be closed and the fourth opened. The three valves which are thus opened and closed together, are the upper steam-valve, the exhausting-valve, and the condensing-valve. The lower steam-valve is to be opened at the same instant that these are closed, and *vice versâ*. The manner of working these valves we shall describe hereafter.

(47.) The process which has just been described, if continued for any considerable number of reciprocations of the piston, would be attended with two very obvious effects which would obstruct and finally destroy the action of the machine. First the condensing water and condensed steam would collect in the condenser D, and fill it, and secondly, the water in the cistern in which the condenser is placed, would gradually become heated, until at last it would not be cold enough to condense the steam when introduced in the jet. Besides this it will be recollected that water boils in a vacuum at a very low temperature (17); and, therefore, the hot water collected in the bottom of the condenser would produce steam which, rising into the cylinder through the exhausting-valve, would resist the descent of the piston, and counteract the effects of the steam above it. A further disadvantage arises from the air or other permanently elastic fluid which enters in the jet in combination with the water, and which is disengaged by its own elasticity in the vacuum produced in the condenser.

To remove these difficulties, a pump is placed near the condenser communicating with it by a valve M, which opens from the condenser into the pump. In this pump is placed a piston which moves air-tight, and in which there is a valve N which opens upwards. Now suppose the piston at the bottom of the pump. As it rises, since the valve in it opens *upwards*, no air can pass *down* through it, and consequently it leaves a vacuum *below* it. The water and any air which may be collected in the condenser open the valve M, and pass into the lower part of the pump, from which they cannot return in consequence of the valve M opening *outwards*. On the descent of the pump-piston, the fluids which occupy the lower part of the pump, force open the piston-valve N, and passing through it get *above* the piston from which their return is prevented by the valve N. In the next ascent, the piston lifts these fluids to the top of the pump, whence they are discharged through a conduit into a small cistern B by a valve K which opens outwards. The water which is thus collected in B is heated by the condensed steam, and is reserved in B which is called the hot-well for feeding the boiler, which is effected by means which we shall presently explain. The pump which draws off the hot water and air from the condenser is called the *air-pump*.

(48.) We have not yet explained the manner in which the valves and the air-pump piston are worked. The rod Q of the latter is connected with the working beam, and the pump is therefore wrought by the engine itself. It is not very material to which arm of the beam it is attached. If it be on the same side of the centre of the beam with the cylinder, it rises and falls with the steam-piston; but if it be on the opposite side, the pump-piston rises when the steam-piston falls, and *vice versâ.* In the single-engine there are some advantages in the latter arrangement. As the steam-piston *descends,* the steam rushes into the condenser, and the jet is playing, and this, therefore, is the most favorable time for drawing out the water and condensed steam from the condenser by the ascent of the pump-piston, since by this means the descent of the steam-piston is assisted, an effect which would not be produced if the steam-piston and pump-piston descended together.

With respect to the method of opening and closing the valves, it is evident that the three valves which are simultaneously opened and closed, may be so connected as to be worked by the same lever. This lever may be struck by a pin fixed upon the rod Q of the air-pump, so that when the pistons have arrived at the top of the cylinders, the pin strikes the lever and opens the three valves. A catch or detent is provided for keeping them open during the descent of the piston, from which they are disengaged in a similar manner on the arrival of the piston at the bottom of the cylinder, and they close by their own weight.

In exactly the same way the lower steam-valve is opened on the arrival of the piston at the bottom of the cylinder, and closed on its arrival at the top by the action of a pin placed on the piston-rod of the air-pump.

(49.) Soon after the invention of these engines, Watt found that in some instances inconvenience arose from the too rapid motion of the steam-piston at the end of its stroke, owing to its being moved with an *accelerated motion*. This was owing to the uniform action of the steam-pressure upon it. For upon first putting it in motion at the top of the cylinder, the motion was comparatively slow, but from the continuance of the same pressure the velocity with which the piston descended was continually increasing, until it reached the bottom of the cylinder where it acquired its greatest velocity. To prevent this, and to render the descent as nearly as possible uniform, it was proposed to cut off the steam before the descent was completed, so that the remainder might be effected merely by the expansion of the steam which was admitted to the cylinder. To accomplish this, he contrived, by means of a pin on the rod of the air-pump, to close the upper steam-valve when the steam-piston had completed one-third of its entire descent, and to keep it closed during the remainder of the descent, and until the piston again reached the top of the cylinder. By this arrangement the steam pressed the piston with its full force through one-third of the descent, and thus put it into motion; during the other two-thirds the steam thus admitted acted merely by its expansive force, which became less in exactly the same proportion as the space given to it by the descent of the piston increased. Thus during the last two-thirds of the descent the piston is urged by a gradually decreasing force which in practice was found just sufficient to sustain in the piston an uniform velocity.

Another advantage gained by this contrivance independently of the uniformity of the motion was, that two-thirds of the fuel were saved; for instead of consuming a cylinder full of steam, each descent of the piston, only one-third of a cylinder full was necessary.

(50.) We have already mentioned the difficulty arising from the water in the cistern, in which the condenser and air-pump are placed, becoming heated, and the condensation therefore being imperfect. To prevent this, a waste-pipe is placed in this cistern, from which the water is continually discharged, and a pump L (called the *cold water pump*) is worked by the engine itself, which raises a supply of cold water and sends it through a pipe in a constant stream into the cold cistern. The waste-pipe, through which the water flows from the cistern, is placed near the top of it, since the heated water being lighter than the cold, remains on the top. Thus the heated water is continually flowing off, and a constant stream of cold water supplied. The piston-rod of the cold water pump is attached to the beam (by which it is worked) usually on the opposite side from the cylinder.

Another pump O (called the *hot water pump*), enters the *hotwell* B, and raising the water from it, forces it through a tube to the boiler for the purpose of feeding it. The manner in which this is effected will be more particularly described hereafter. A part of the heat which would otherwise be lost, is thus restored to the boiler to assist in the production of fresh steam. We may consider a portion of the heat to be in this manner *circulating* continually through the machine. It proceeds from the boiler in steam; works the piston, passes into the condenser, and is reconverted into hot water; thence it is passed to the hot-well, from whence it is pumped back into the boiler, and is again converted into steam, and so proceeds in constant circulation.

(51.) From what has been described, it appears that there are four pistons attached to the great beam and worked by the piston of the steam-cylinder. On the same side of the centre with the cylinder is the piston-rod of the air-pump, and on the opposite side are the piston-rods of the hot water pump and the cold water pump; and lastly, at the extremity of the beam opposite to that at which the steam-piston works, is the piston of the pump to be wrought by the engine.

(52.) The position of these piston-rods with respect to the centre of the beam depends on the play necessary to be given to the piston. If the play of the piston be short, its rod will be attached to the beam near the centre, and if longer, more remote from the centre. The cylinder of the air-pump is commonly half the length of the steam-cylinder, and its piston-rod is attached to the beam at the point exactly in the middle between the end of the beam and the centre. The hot water pump not being required to raise a considerable quantity of water, its piston requires but little play, and is, therefore, placed near the centre of the beam, the piston-rod of the cold water pump being farther from the centre.

(53.) It appears to have been about the year 1763, that Watt made these improvements in the steam-engine and constructed a model which fully realized his expectations. Either from want of influence or the fear of prejudice and opposition, he did not make known his discovery or attempt to secure it by a patent at that time. Having adopted the profession of a land surveyor, his business brought him into communication with Dr. Roebuck, at that time extensively engaged in mining speculations, who possessed some command of capital, and was of a very enterprising disposition. By Roebuck's assistance and countenance, Watt erected an engine on the new construction at a coal mine on the estate of the Duke of Hamilton, at Kinneil near Burrowstoness. This engine being a kind of experimental one, was improved from time to time as circumstances suggested, until it reached considerable perfection. While it was being erected, Watt in conjunction with Roebuck applied for and obtained a patent to secure the property in the invention. This patent was enrolled in 1769, six years after Watt invented the improved engine.

Watt was now preparing to manufacture the new engines on an extensive scale, when his partner Roebuck suffered a considerable loss by the failure of a mining speculation in which he had engaged, and became involved in embarrassments, so as to be unable to make the pecuniary advances necessary to carry Watt's designs into execution. Again disappointed, and harassed by the difficulties which he had to encounter, Watt was about to relinquish the further prosecution of his plans, when Mr. Matthew Bolton, a gentleman who had established a factory at Birmingham a short time before, made proposals to purchase Dr. Roebuck's share in the patent, in which he succeeded; and in 1773, Watt entered into partnership with Bolton.

His situation was now completely changed. Bolton was not only a man of extensive capital, but also of considerable personal influence, and had a disposition which led him, from taste, to undertakings which were great and difficult, and which he prosecuted with the most unremitting ardency and spirit. "Mr. Watt," says Playfair, "was studious and reserved, keeping aloof from the world; while Mr. Bolton was a man of address, delighting in society, active and mixing with people of all ranks with great freedom, and without ceremony. Had Mr. Watt searched all Europe, he probably would not have found another person so fitted to bring his invention before the public, in a manner worthy of its merit and importance; and although of most opposite habits, it fortunately so happened, that no two men ever more cordially agreed in their intercourse with each other."

The delay in the progress of the manufacture of engines occasioned by the failure of Dr. Roebuck was such, that Watt found that the duration of his patent would probably expire before he would even be reimbursed the necessary expences attending the various arrangements for the manufacture of the engines. He therefore, with the advice and influence of Bolton, Roebuck and other friends, in 1775, applied to parliament for an extension of the term of his patent, which was granted for 25 years from the date of his application, so that his exclusive privilege should expire in 1800.

An engine was now erected at Soho (the name of Bolton's factory) as a specimen for the examination of mining speculators, and the engines were beginning to come into demand. The manner in which Watt chose to receive remuneration from those who used his engines was as remarkable for its ingenuity, as for its fairness and liberality. He required that one-third of the saving of coals effected by his engines compared with the atmospheric engines hitherto used, should be paid to him, leaving the benefit of the other two-thirds to the public. Accurate experiments were made to ascertain the saving of coals:

and as the amount of this saving in each engine depended on the length of time it was worked, or rather on the number of descents of the piston, Watt invented a very ingenious method of determining this. The vibrations of the great working beam were made to communicate with a train of wheelwork in the same way as those of a pendulum communicate with the work of a clock. Each vibration of the beam moved one tooth of a small wheel, and the motion was communicated to a hand or index, which moved on a kind of graduated plate like the dial plate of a clock. The position of this hand marked the number of vibrations of the beam. This apparatus which was called the *counter,* was locked up and secured by two different keys, one of which was kept by the proprietor, and the other by Bolton and Watt, whose agents went round periodically to examine the engines, when the counters were opened by both parties and examined, and the number of vibrations of the beam determined, and the value of the patent third found.*

Notwithstanding the manifest superiority of these engines over the old atmospheric engines, yet such were the influence of prejudice and the dislike of what is new, that Watt found great difficulties in getting them into general use. The comparative first cost also probably operated against them, for it was necessary that all the parts should be executed with great accuracy, which entailed proportionally increased expense. In many instances they felt themselves obliged to induce the proprietors of the old atmospheric engines to replace them by the new ones, by allowing them in exchange an exorbitant price for the old engines, and in some cases they were induced to erect engines at their own expense, upon an agreement that they should only be paid if the engines were found to fulfil the expectations, and brought the advantages which they promised. It appeared since, that Bolton and Watt had actually expended a sum of nearly £50,000 on these engines before they began to receive any return. When we contemplate the immense advantages which the commercial interests of the country have gained by the improvements in the steam-engine, we cannot but look back with disgust at the influence of that fatal prejudice which opposes the progress of improvement under the pretence of resisting innovation. It would be a problem of curious calculation to determine what would have been lost to the resources of this country, if chance had not united the genius of such a man as Watt with the spirit, enterprize, and capital, of such a man as Bolton! The result would reflect little credit on those who think novelty alone a sufficient reason for opposition.

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* The extent of the saving in fuel may be judged from this: that for three engines erected at Chacewater mine in Cornwall, it was agreed by the proprietors, that they would compound for the patent third, at £2400 per annum; so that the whole saving must have exceeded £7200 per annum.

LECTURE VI.

Defects of the single engine as applied to move machinery — Attempts to remove these — by two single engines — by the double acting engine — Its principle — parallel motion — Crank — Sun and planet wheel — Fly-wheel — Governor.

(54.) In the atmospheric engine, and the improved steam-engine of Watt, the power was of an intermitting kind. It acted only during the descent of the piston, but during the ascent its agency was suspended. Besides this, the weights or counter-poises which lifted the piston in the ascent, acted against the power in the descent; and therefore no power was really saved by the suspension of the agency of steam-pressure during the ascent; since a proportionably increased pressure was produced in the descent. Besides, being of an intermitting nature, the power acted only in one direction. If the steam-engine were only applied to pumping, these would not be defects, since an intermitting force acting always in one direction is that which is required. But if a more extended application of the powers of this machine be contemplated, these defects become serious obstacles. To drive any species of machinery, a constant and uniform action is requisite, and, therefore, the suspension of the power during the ascent of the piston, would be incompatible with this.

Watt first proposed removing this defect by placing a cylinder under each arm of the beam, so that when one piston would be rising, the other would be falling. Thus the power would be acting on each, exactly at the time when its action on the other would be suspended, and an uniformity would be produced by making both cylinders communicate with the same boiler, so that steam of the same pressure would act upon them. They might also communicate with the same condenser, so that the same degree of condensation and a similar vacuum would be produced in each, thus insuring an equality of action.

(55.) This arrangement, however, was soon laid aside in favour of the single cylinder, with steam pressing the piston both *upwards* and *downwards*. This was easily accomplished by opening alternate communications, by valves, between each end of the cylinder, and the boiler and condenser. Thus, when the piston is at the top of the cylinder, steam is admitted from the boiler above the piston, while the steam below it is allowed to flow into the condenser; and when the piston is at the bottom of the cylinder, steam is admitted from the boiler below it, while that which is above it is allowed to flow into the condenser. There is thus a vacuum formed in the cylinder, alternately, above and below the piston, into which the steam admitted on the other side presses it. Such is the principle of what is called the *double-acting steam-engine*, in contradistinction to that in which, as described in the last lecture, steam acts only on one side of the piston, while a vacuum is produced only on the other side.

In this case, the process of condensation must be constantly sustained in the condenser, for when the piston is descending, the steam *below* it is being condensed, and when it is ascending, the steam *above* it is being condensed. The jet must therefore be kept constantly playing in the condenser, and the quantity of water which it admits, is regulated by a valve adjusted by a lever or index which moves upon a graduated arch, and which may be regulated by the engineer when the engine is set at work.

(56.) This change in the action of the first mover occasioned a necessity for a change in the manner of connecting the piston-rod with the beam. In the single-acting engine, the end of the beam *pulled* the piston-rod *up*, and the piston-rod *pulled* the end of the beam *down*. In both those cases, therefore, a flexible chain, applying itself to the arch-head of the beam, evidently transmitted the force. But in the double-acting engine it is quite otherwise. In the descent, it is true, that the piston-rod still *pulls* the beam *down*, but in the ascent the beam no longer *pulls up* the piston-rod, but is *pushed up* by it. Now, a flexible chain, though an effective agent in transmitting that modification of force called a *pull*, is incapable of communicating a *push* or *thrust*. Were the chain and arch-head to be used in a double engine, (which has no counter weight on the opposite end of the beam to pull it up) the consequence would be that, in the ascent of the piston, the chain would slacken, and the end of the beam above the piston-rod still remain depressed.

It is, therefore, necessary that the connexion of the piston-rod with the end of the beam should not be flexible but rigid, so as to be capable of transmitting force, both by *pulling* and *pushing*. Watt first proposed effecting this by making the piston-rod terminate in a rack with teeth, which should play in corresponding teeth raised on the arch head of the beam as in fig. 13.

(57.) Against this method, however, there were some objections, as it was liable to wear, and failed to give that smoothness of motion to the piston-rod which is essentially necessary for the preservation of the condition of the engine. The problem, therefore, which presented itself for solution, was to convert a perfectly smooth and straight motion of the piston-rod into a circular motion in the end of the beam,* and the genius of Watt never was more clearly manifested than in his solution of this problem.

He conceived the notion of two straight rods A B, C D (fig. 14.) moving on centres or pivots A and C, so that the ends B and D would move in arcs of circles, with A and C as centres. The extremities B and D of these rods he conceived to be connected by a third rod B D, being united with them by pivots at B and D, on which it could turn freely. To the system of rods thus connected, let an alternate motion on the fixed centres A and C be communicated. The points B and D will move in arcs with centres at A and C respectively, but the middle point P of the connecting-rod B D will move upwards and downwards in a straight line.*

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* Technically, "to convert a reciprocating rectilinear motion into a reciprocating circular motion."

His manner of reducing this mathematical principle to practical application was as elegant as the notion itself was ingenious.

The apparatus is represented on the arm of the beam which works the piston in fig. 15. The beam, moving on its axis C, every point in its arm moves in the arc of a circle of which C is the centre. Let B be the point which divides the arm A C into equal parts, A B and B C: and let D E be a straight rod equal in length to C B, and playing on the fixed centre or pivot D. The end E of this rod is connected by a straight bar E B with the point B, by pivots at B and E, on which the rod B E turns freely. If the beam be supposed to move alternately on its axis C, the point B will move up and down in a circular arc, of which C is the centre; and at the same time the point E will move in an equal circular arc round the point D as a centre. According to what we have just explained, the middle point F of the rod B E will move up and down in a straight line.

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* In a strict mathematical sense, the path of the point P is a curve of an high order, but in the play which is given to it in the application used in the steam-engine, it describes only a part of its entire locus, and this part extending equally on each side of a point of inflection, its radius of curvature is infinite, so that in practice, the deviation from a straight line, when proper proportions are observed in the rods, is imperceptible.

Also, let a rod A G, equal in length to B E, be attached to the end A of the beam by a pivot on which it moves freely; and let its extremity G be connected with E by a rod G E, equal in length to A B, and playing on pivots at G and E. The point G will move in a straight line parallel to that in which F moves.* The piston-rod of the steam-piston is attached to the point G, and that of the air-pump is attached to the point F, so that they are thus moved in parallel straight lines, one having double the motion of the other, being double the distance from the centre C.†

This beautiful contrivance is called the *parallel motion:* and is an instance of the result of a complicated mathematical analysis perceived instinctively, and apparently without any chain of connected reasoning. Watt was asked by those whose admiration was justly excited by this exquisite invention, to what reasoning he could trace back his discovery; and he replied that he was aware of none; that the conception flashed upon his mind without previous investigation, and so as to excite in himself surprise at the perfection of its action; and that at looking at it for the first time, he experienced all that pleasureable sense of novelty which arises from the first contemplation of the results of the invention of others.

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* The points C, F and G evidently lie in the same straight line, since CB : CA :: BF : AG, and the latter lines are parallel. Taking C as the common *pole* of the *loci* of the points F, G, the *radius vector* of the one will always be twice the corresponding *radius vector* of the other; and, therefore, these curves are similar, similarly placed and parallel. Hence, by the last note, the point G must move in a line, differing imperceptibly from a right line.

† It is not necessary that the rods, forming the parallel motion, should have the proportions which we have assigned to them. There are various proportions which answer the purpose, and which will be seen by reference to works on the steam-engine.

This and the other inventions of Watt seem to have been the pure creations of his genius, very little assisted by the results of practice. It does not even appear that he was a dexterous mechanic; for he never assisted in the constructions of the first models of his own inventions. His dwelling-house was two miles from the factory, to which he never went more than once in the week, and then did not stay half an hour.

(58.) A perfect method being thus obtained of conveying the alternate motion of the piston to the working beam, the use of a counterpoise to lift the piston was discontinued, and the beam was made to balance itself exactly on its centre. The next end to be obtained was to adapt the vibrating force of the working end of the beam to the motion of machinery. The motion most generally useful for this purpose is one of *continued rotation.* The object, therefore, was by the *alternate circular* motion of the end of the beam to produce a *continued circular* motion. In the first instance, Watt proposed effecting this by a *crank,* connected with the working end of the beam by a metal connector or rod.

Let K be the centre or axis of the wheel which works the machinery, and to which rotation is to be imparted by the beam C H. On the axle K, suppose a lever K I fixed, so that when K I is turned round the centre K, the wheel must be turned with it. Let a connector or rod H I be attached to the points H and I, playing freely on pivots or joints. As the end H is moved upwards and downwards, the lever K I is turned round the centre K, so as to give a continued rotatory motion to the wheel which revolves on that centre. The different positions which the connector and lever K I assume in the different parts of a revolution are represented in fig. 16.

(59.) This was the first method which occurred to Watt for producing a continued rotatory motion by means of the vibrating motion of the beam, and is the method now universally used. A workman, however, from Mr. Watt's factory, who was aware of the construction of a model of this, communicated the method to Mr. Washborough of Bristol, who anticipated Watt in taking out a patent, and although it was in his power to have disputed the patent, yet rather than be involved in litigation, he gave up the point, and contrived another way of producing the same effect, which he called the *sun and planet* wheel, and which he used until expiration of the Washborough's patent, when the crank was resumed.

The toothed wheel B (fig. 17.) is fixed on the end of the connector, so that it does not turn on its axis. The teeth of this wheel work in those of another wheel A which is the wheel to which rotation is to be imparted, and which is turned by the wheel B revolving round it, urged by the rod H I, which receives its motion from the working-beam. The wheel A is called the sun-wheel, and B the planet wheel, from the obvious resemblance to the motion of these bodies.

This contrivance, although in the main inferior to the more simple one of the crank, is not without some peculiar advantages; among others, it gives to the sun-wheel double the velocity which would be communicated by the simple crank, for in the simple crank one revolution only of the axle is produced by one revolution of the crank, but in the sun-and-planet wheel two revolutions of the sun-wheel are produced by one of the planet-wheel; thus a double velocity is obtained from the same motion of the beam. This will be evident from considering that when the planet-wheel is in its highest position, its lowest tooth is engaged with the highest tooth of the sun-wheel; as the planet-wheel passes from the highest position, its teeth driving those of the sun-wheel before them, when it comes into the lowest position, the highest tooth of the planet-wheel is engaged with the lowest of the sun-wheel: but then half of the sun-wheel has *rolled off* the planet-wheel, and therefore, the tooth which was engaged with it in its highest position, must now be distant from it by half the circumference of the wheel. A little reflection, however, on the nature of the motion, will render this plainer than any description can. This advantage of giving an increased velocity, may be obtained also by the simple crank, by placing toothed wheels on its axle. Independently of the greater expense attending the construction of the sun-and-planet wheel, its liability to go out of order, and the rapid wear of the teeth and other objections, rendered it decidedly inferior to the crank, which has now entirely superseded it.

(60.) Whether the simple crank or the sun-and-planet wheel be used, there is a difficulty of a peculiar nature attending the continuance of the rotatory motion which is still to be overcome. There are two positions in which the engine can give no motion whatever to the crank, and these are when the end of the beam, the axle of the crank, and the pivot which joins the connector with the crank, are in the same straight line. This will be easily understood. Suppose the beam, connector, and crank to assume the position represented in fig. 15. If steam urge the piston downwards, the point H and the connector H I will be drawn directly upwards. But it must be very evident that in the present situation of the connector H I, and the lever I K, the force which draws the point I in the direction I K can have no effect whatever in turning I K round the centre K, but will merely exert a pressure on the axle or pivots of the wheel.

Again, suppose the crank and connector to be in the position H I K (fig. 16.), the piston being consequently at the bottom of the cylinder. If steam now press the piston *upwards*, the pivot H and the connector H I will be pressed *downwards*, and this pressure will urge the crank I K in the direction I K. It is evident that such a force cannot turn the crank round the centre K, and can be attended with no other effect than a pressure on the axle or pivots of the wheel.

Hence in these two positions, the engine can have no effect whatever in turning the crank. What then, it may be asked, extricates the machine from the mechanical dilemma in which it is placed twice in every revolution, on arriving at those positions in which the crank escapes the influence of the power? There is a tendency in bodies, when once put in motion, to continue that motion until stopped by some opposing force, and this tendency carries the crank out of those two critical situations. The velocity which is given to it, while it is under the influence of the impelling force of the beam, is retained in a sufficient degree to carry it through that situation in which it is deserted by this impelling force. Although the rotatory motion intended to be produced by the crank is, therefore, not absolutely impeded by this circumstance, yet it is rendered extremely irregular, since, in passing through the two positions already described, where the machine loses its power over the crank, the motion will be very slow, and, in the positions of the crank most remote from these, where the power of the beam upon it is greatest, the motion will be very quick. As the crank revolves from each of those positions where the power of the machine over it is greatest, to where that power is altogether lost, it is continually diminished, so that in fact the crank is driven by a varying power, and so produces a varying motion. This will be easily understood by considering the successive positions of the crank and connector represented in fig. 16.

This variable motion becomes particularly objectionable when the engine is employed to drive ma chinery. To remove this defect, we have recourse to the property of bodies just mentioned, viz. their tendency to retain a motion which is communicated to them. A large metal wheel called a *fly-wheel* is placed upon the axis of the crank (fig. 15.), and is turned by it. The effect of this wheel is to equalize the motion communicated by the action of the beam on the crank, that action being just sufficient to sustain in the fly-wheel an uniform velocity, and the tendency of this wheel to retain the velocity it receives, renders its rotation sufficiently uniform for all practical purposes.

This uniformity of motion, however, will only be preserved on two conditions, *first*, that the supply of steam from the boiler shall be uniform, and secondly that the machine have always the same resistance to overcome or be *loaded* equally. If the supply of steam from the boiler to the cylinder be increased, the motion of the piston will be rendered more rapid, and, therefore, the revolution of the fly-wheel will also be more rapid, and on the other hand a diminished supply of steam will retard the fly-wheel. Again, if the resistance or load upon the engine be diminished, the supply of steam remaining the same, the velocity will be increased, since a less resistance is opposed to the energy of the moving power, and on the other hand, if the resistance or load be increased, the speed will be diminished, since a greater resistance will be opposed to the same moving power. To insure an uniform velocity, in whatever manner the load or resistance may be changed, it is necessary to proportion the supply of steam to the resistance, so that upon the least variation in the velocity, the supply of steam will be increased or diminished, so as to keep the engine going at the same rate.

(61.) One of the most striking and elegant appendages of the steam-engine is the apparatus contrived by Watt for effecting this purpose. An apparatus, called a *regulator* or *governor*, had been long well known to mill-wrights for rendering uniform the action of the stones in corn mills, and was used generally in machinery. Mr. Watt contrived a beautiful application of this apparatus for the regulation of the steam-engine. In the pipe which conducts steam from the boiler to the cylinder he placed a thin circular plate, so that when placed with its face presented towards the length of the pipe, it nearly stopped it, and allowed little or no steam to pass to the cylinder, but when its edge was placed in the direction of the pipe, it offered no resistance whatever to the passage of the steam. This circular plate was made to turn on a diameter as an axis, passing consequently through the centre of the tube. This plate or valve, called the throttle valve, was turned by a lever outside the tube, and according to the position given to it, would permit more or less steam to pass. If the valve be placed with its edge nearly in the direction of the tube, the supply of steam is abundant; if it be placed with its face nearly in the direction of the tube, the supply of steam is more limited, and it appears that by the position given to this valve, the steam may be measured in any quantity to the cylinder.

At first it was proposed that the engine-man should adjust this valve with his hand; when the engine was observed to increase its speed too much, he would check the supply of steam by partially closing the valve, but if on the other hand the motion was too slow, he would open the valve and let in a more abundant supply of steam. Watt, however, was not content with this, and desired to make the engine itself discharge this task with more steadiness and regularity than any attendant could, and for this purpose he applied the governor already alluded to.

This apparatus is represented in fig. 15; L is a perpendicular shaft or axle to which a wheel M with a groove is attached, and which turns with the shaft in pivots at the ends of the shaft L. A strap or rope which is rolled upon the axle of the fly-wheel is passed round the groove in the wheel M, in the same manner as the strap acts in a turning lathe. By means of this strap the rotation of the fly-wheel will produce a rotation of the wheel M and the shaft L, and the speed of the one will always increase or diminish in the same proportion as the speed of the other. N, N are two heavy balls of metal placed at the ends of rods, which play on an axis fixed on the revolving shaft at O, and extend beyond the axis to Q, Q. Connected with these by joints at Q Q are two other rods Q R, which are attached to a broad ring of metal, moving freely up and down the revolving shaft. This ring is attached to a lever whose centre is S, and is connected by a series of levers with the throttle-valve T. When the speed of the fly-wheel is much increased, the spindle L is whirled round with considerable rapidity, and by their natural tendency[*] the balls N N fly from the centre. The levers which play on the axis O, by this motion, diverge from each other, and, thereby depress the joints Q Q, and by this draw down the joints R, and with them the ring of metal which slides upon spindle. By these means the end of the lever playing on S is depressed, and the end V raised, and the motion is transmitted to the throttle-valve which is thereby partially closed, and the supply of steam to the cylinder checked. If, on the contrary, the velocity of the fly-wheel be diminished, the balls will fall towards the axis, and the opposite effects ensuing, the supply of steam will be increased, and the velocity restored.

The peculiar beauty of this apparatus is, that in whatever position the balls settle themselves, the velocity with which the governor revolves must be the same;[†] and in this, in fact, consists its whole efficacy as a regulator. Let us suppose that the en-

[*] The *centrifugal force*.

[†] Strictly speaking, this is only true when the divergence of the rods from the spindle is not very great, and in practice, this divergence is never sufficient to render the above assertion untrue. This property of the conical pendulum arises from the circumstance of the centrifugal force, in this instance, varying as the radius of the circle in which the balls are moved; and when this is the case, as is well known, the *periodic time* is constant. The time of one revolution of the balls is equal to twice the time in which either ball, as a common pendulum, would vibrate on the centre, and as all its vibrations, though the arcs be unequal, are equal in time,

gine is working 100 looms, and that 50 of them are thrown out of gear. The engine is thus suddenly relieved of half its load, and the supply of steam before employed, will now make it move with a considerably increased velocity. The balls will immediately fly from the axis and partially close the throttle-valve, and diminish the supply of steam. When this is so far accomplished as to restore the engine to its former velocity, the balls will become steady, and continue to revolve at the increased distance from the axis with the same velocity as they before revolved at the original distance.

We have thus described the principal parts of the double-acting steam-engine. The valves and the methods of working them have been reserved for the next lecture, as they admit of considerable variety, and will be better treated of separately. We have also reserved the consideration of the boiler, which is far from being the least interesting part of the modern steam-engine, for a future lecture.

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provided those arcs be small, so also is the periodic time of the revolving balls invariable. These observations, however, only apply when the balls settle themselves steadily into a circular motion; for while they are ascending they describe a a spiral curve with double curvature, and the period will vary. This takes place during the momentary changes in the velocity of the engine.

LECTURE VII.

On the Valves of the double-acting Steam-Engine — Original Valves — Spindle Valves — Sliding Valve — D Valve — Four-way Cock.

(62.) The various improvements described in the last lecture were secured to Watt by patent in the year 1782. The engine now acquired an enlarged sphere of action; for its dominion over manufactures was decided by the *fly-wheel, crank,* and *governor.* By means of these appendages, its motions were regulated with the most delicate precision; so that while it retained a power whose magnitude was almost unlimited, that power was under as exact regulation as the motion of a time-piece. There is no species of manufacture, therefore, to which this machine is not applicable, from the power which spins the finest thread, or produces the most delicate web, to that which is necessary to elevate the most enormous weights, or overcome the most unlimited resistances. Although it be true, that in later times the steam-engine has received many improvements, some of which are very creditable to the invention and talents of their projectors, yet it is undeniably certain, that all its great and leading perfections, all those qualities by which it has produced such wonderful effects on the resources of these countries, by the extension of manufactures and commerce,—those qualities by which its influence is felt and acknowledged in every part of the civilized globe, in increasing the happiness, in multiplying the enjoyments, and cheapening the pleasures of life,—that these qualities are due to the predominating powers of one man, and that man one who possessed neither the influence of wealth, rank, nor education, to give that first impetus which is so often necessary to carry into circulation the earlier productions of genius.

The method of working the valves of the double-acting steam-engine is a subject which has much exercised the ingenuity of engineers, and many elegant contrivances have been suggested, some of which we shall now proceed to describe. But even in this the invention of Watt has anticipated his successors; and the contrivances suggested by him are those which are now almost universally used.

In order perfectly to comprehend the action of the several systems of valves which we are about to describe, it will be necessary distinctly to remember the manner in which the steam is to be communicated to the cylinder, and withdrawn from it. When the piston is at the top of the cylinder, the steam below it is to be drawn off to the condenser, and the steam from the boiler is to be admitted above it. Again, when it has arrived at the bottom of the cylinder, the steam above is to be drawn off to the condenser, and the steam from the boiler is to be admitted below it.

In the earlier engines constructed by Watt, this was accomplished by four valves, which were opened and closed in pairs. Valve boxes were placed at the top and bottom of the cylinder, each of which communicated by tubes with both the steam-pipe from the boiler and the condenser. Each valve-box accordingly contained two valves, one to admit steam from the steam-pipe to the cylinder, and the other to allow that steam to pass into the condenser. Thus each valve-box contained a steam valve and an exhausting valve. The valves at the top of the cylinder are called the *upper steam valve,* and the *upper exhausting valve,* and those at the bottom, the *lower steam valve* and the *lower exhausting valve.* In fig. 15. A′ is the upper steam valve, which when open admits steam above the piston ; B′ is the upper exhausting valve, which when open draws off the steam from the piston to the condenser. C′ is the lower steam valve, which admits steam below the piston, and D′ the lower exhausting valve, which draws off the steam from below the piston to the condenser.

Now, suppose the piston to be at the top of the cylinder, the cylinder below it being filled with steam, which has just pressed it up. Let the *upper steam valve* A′, and the *lower exhausting valve* D′ be opened, and the other two valves closed. The steam which fills the cylinder below the piston will immediately pass through the valve D′ into the condenser, and a vacuum will be produced below the piston. At the same time, steam is admitted from the steam-pipe through the valve A′ above the piston, and its pressure will force the piston to the bottom of the cylinder. On the arrival of the piston at the bottom of the cylinder, the upper steam valve A′, and lower exhausting valve D′, are closed; and the lower steam valve C′, and upper exhausting valve B′ are opened. The steam which fills the cylinder above the piston now passes off through B′ into the condenser, and leaves a vacuum above the piston. At the same time, steam from the boiler is admitted through the lower steam valve C′, below the piston, so that it will press the piston to the top of the cylinder; and so the process is continued.

It appears, therefore, that the upper steam valve, and the lower exhausting valve, must be opened together, on the arrival of the piston at the top of the cylinder. To effect this, one lever E′ is made to communicate by jointed rods with both these valves, and this lever is moved by a pin placed on the piston-rod of the air-pump; and such a position may be given to this pin as to produce the desired effect exactly at the proper moment of time. In like manner, another lever F′ communicates by jointed rods with the upper exhausting valve and lower steam valve, so as to open them and close them together; and this lever in like manner is worked by a pin in the piston-rod of the air-pump.

(63.) This method of connecting the valves, and working them, has been superseded by another, for which Mr. MURRAY of Leeds obtained a patent, which was, however, set aside by Messrs. Bolton and Watt, who shewed that they had previously practised it. This method is represented in fig. 18, 19. The stems of the valves are perpendicular, and move in steam-tight sockets in the top of the valve-boxes. The stem of the upper steam valve A is a tube through which the stem of the upper exhausting valve B passes, and in which it moves steam-tight; both these stems moving steam-tight through the top of the valve-box. The lower steam valve C, and exhausting valve D, are similarly circumstanced; the stem of the former being a tube through which the stem of the latter passes. The stems of the upper steam valve and lower exhausting valve are then connected by a rod E; and those of the upper exhausting valve and lower steam valve by another rod F. These rods, therefore, are capable of moving the valves in pairs, when elevated and depressed. The motion which works the valves is, however, not communicated by the rod of the air-pump, but is received from the axis of the fly wheel. This axis works an apparatus called an *eccentric;* the principle which regulates the motion of this may be thus explained:

D E (fig. 20, 21.) is a circular metallic ring, the inner surface of which is perfectly smooth. This ring is connected with a shaft F B, which communicates motion to the valves by levers which are attached to it at B. A circular metallic plate is fitted in the ring so as to be capable of turning within it, the surfaces of the ring and plate which are in contact being smooth and lubricated with oil or grease. This circular plate revolves, but not on its centre. It turns on its axis C, at some distance from its centre A; the effect of which, evidently, is that the ring within which it is turned is moved alternately in opposite directions, and through a space equal to twice the distance (C A) of the axis of the circular plate from the common centre of it and the ring. The eccentric in its two extreme positions is represented in fig. 20, 21. The plate and ring D E are placed on the axis of the fly-wheel, or on the axis of some other wheel which is worked by the fly-wheel. So that the motion of continued rotation in the fly-wheel is thus made to produce an alternate motion in a straight line in the shaft F B. This rod is made to communicate by levers with the rods E and F (fig. 18, 19), which work the valves in such a manner, that when the eccentric is in the position fig. 20, one pair of valves are opened and the other pair closed; and when it is brought to the position fig. 21, the other pair are opened, and the former closed, and so on. It is by means of such an apparatus as this, that the valves are worked almost universally at present.

The piston being supposed to be at the top of the cylinder (fig. 18.) and the rod E raised, the valves A and D are opened, and B and C closed. The steam enters from the steam-pipe at an aperture immediately above the valve A, and passing through the open valve, enters the cylinder above the piston. At the same time, the steam which is below the piston, and which has just pressed it up, flows through the open valve D, and through a tube immediately under it to the condenser. A vacuum being thus produced below the piston, and steam pressure acting above it, it descends, and when it arrives at the bottom of the cylinder (fig. 19.) the rod F is drawn down, and the valves A and D fall into their seats, and at the same time the rod F is raised, and the valves B and C are opened. Steam is now admitted through an aperture above the valve C, and passes below the piston, while the steam above it passes through the open valve B into a tube immediately under it, which leads to the condenser. A vacuum being thus produced above the piston, and steam pressure acting below it, the piston ascends, and thus the alternate ascent and descent is continued by the motion communicated to the rods E F from the fly-wheel.

(64.) There are various other contrivances for regulating the circulation of steam through the cylinder. In fig. 22. 23. is represented a section of a slide valve suggested by Mr. Murray of Leeds. The steam-pipe from the boiler enters the valve-box D E at S. Curved passages A A, B B, communicate between this valve-box and the top and bottom of the cylinder; and a fourth passage leads to the tube C, which passes to the condenser. A sliding piece within the valve-box opens a communication alternately between each end of the cylinder, and the tube C which leads to the condenser. In the position of the apparatus in fig. 22. steam is passing from the steam-pipes, through the curved passage A A above the piston, and at the same time the steam below the piston is passing through the passage B B into the tube C, and thence to the condenser. A vacuum is thus formed below the piston, and steam is introduced above it. The piston, therefore, descends; and when it arrives at the bottom of the cylinder, the slide is moved into the position represented in fig. 23. Steam now passes from S through B B below the piston, and the steam above it passes through A A and C to the condenser.

A vacuum is thus produced above the piston, and steam pressure is introduced below it, and the piston ascends; and in this way the motion is continued.

The slide is moved by a lever, which is worked by the eccentric from the fly-wheel.

(65.) Watt suggested a method of regulating the circulation of steam, which is called the D valve, from the resemblance which the horizontal section of the valve has to the letter D. This method, which is very generally used, is represented in section in fig. 24. 25. Steam from the boiler enters through S. A rod of metal connects two solid plugs A B, which move steam-tight in the passage D. In the position of the apparatus represented in fig. 24. the steam passes from S through the passage D, and enters the cylinder above the piston, while the steam below the piston passes through the open passage by the tube C to the condenser. A vacuum is thus formed below the piston, while the pressure of steam is introduced above it, and it accordingly descends. When it has arrived at the bottom of the cylinder, the plugs A B are moved into the position in fig. 25. Steam now passing from S through D, enters the cylinder below the piston; while the steam which is above the piston, and has just pressed it down, passes through the open passage into the condenser. A vacuum is thus produced above the piston, and the steam pressure below forces it up. When it has arrived at the top of the cylinder, the position of the plugs A B is again changed to that represented in fig. 24. and a similar effect to that already described is produced, and the piston is pressed down; and so the process is continued.

The plugs A B, and the rod which connects them, are moved up and down by proper levers, which receive their motion from the eccentric.

This contrivance is frequently modified, particularly in cases where the engine is not of very great power, by conducting the steam from above the piston to the condenser, through a tube in the plugs A B, and their connecting rod. In fig. 26. 27. a tube passes through the plugs A B and the rod which joins them. In the position fig. 26. steam entering at S passes through the tube to the cylinder above the piston, while the steam below the piston passes through C into the condenser. A vacuum being thus made below the piston, and steam pressing above it, it descends; and when it has arrived at the bottom of the cylinder, the position of the plugs A B and tube is changed to that represented in fig. 27. The steam now entering at S passes to the cylinder below the piston, while the steam above the piston passes through C into the condenser. A vacuum is thus produced above the piston, and steam pressure introduced below it, so that it ascends. When it has arrived at the top of the cylinder, the plugs are moved into the position represented in fig. 26. and similar effects being produced, the piston again descends; and so the motion is continued.

The motion of the sliding tube may be produced as in the former contrivances, by the action of the eccentric. It is also sometimes done by a bracket fastened on the piston-rod. This bracket, in the descent of the piston, strikes a projection on the valve-rod, and drives it down, and in the ascent meets a similar projection, and raises it.

(66.) Another method, worthy of notice for its elegance and simplicity, is the *four-way cock*. A section of this contrivance is given in fig. 28. 29. C T S B are four passages or tubes; S leads from the boiler, and introduces steam; C, opposite to it, leads to the condenser; T is a tube which communicates with the top of the cylinder; and B one which communicates with the bottom of the cylinder. These four tubes communicate with a cock which is furnished with two curved passages, as represented in the figures; and these passages are so formed, that according to the position given to the cock, they may be made to open a communication between any two adjacent tubes of the four just mentioned. When the cock is placed as in fig. 28. communication is opened between the steam-pipe and the top of the cylinder by one of the curved passages, and between the condenser and the bottom of the cylinder by the other curved passage. In this case the steam passes from below the piston to the condenser, leaving a vacuum under it, and steam is introduced from the boiler above the piston. The piston therefore descends; and when it has arrived at the bottom of the cylinder, the position of the cock is changed to that represented in fig. 29. This change is made by turning the cock through one fourth of an entire revolution, which may be done by a lever moved by the eccentric, or by various other means. One of the curved passages in the cock now opens a communication between the steam-pipe and the bottom of the cylinder; while the other opens a communication between the condenser and the top of the cylinder. By these means, the steam from the boiler is introduced below the piston, while the steam above the piston is drawn off to the condenser. A vacuum being thus made above the piston, and steam introduced below it, it ascends; and when it has arrived at the top of the cylinder, the cock being moved back, it resumes the position in fig. 28. and the same consequences ensue, the piston descends, and so the process is continued. In fig. 30. 31. the four-way cock with the passages to the top and bottom of the cylinder is represented on a larger scale.

This beautiful contrivance is not of late invention. It was used by Papin, and is also described by Leupold in his *Theatrum Machinarum*, a work published about the year 1720, in which an engine is described acting with steam of high pressure, on a principle which we shall describe in a subsequent lecture.

The four-way cock is liable to some practical objections. The quantity of steam which fills the tubes between the cock and the cylinder, is wasted every stroke. This objection, however, also applies to the sliding valve (fig. 22. 23.) and to the sliding tube or D valves (fig. 24. 25. 26. 27.) In fact, it is applicable to every contrivance in which means of shutting off the steam are not placed at both top and bottom of the cylinder. Besides this, however, the various passages and tubes cannot be conveniently made large enough to supply steam in sufficient abundance, and consequently it becomes necessary to produce steam in the boiler of a more than ordinary strength to bear the attenuation which it suffers in its passage through so many narrow tubes.

One of the greatest objections, however, to the use of the four-way cock, particularly in large engines, is its unequal wear. The parts of it near the passages having smaller surfaces, become more affected by the friction, and in a short time the steam leaks between the cock and its case, and becomes wasted, and tends to vitiate the vacuum. These cocks are, therefore, seldom used, except in small condensing engines; but are almost universally adopted in high-pressure steam-engines; for in these the leakage is not of so much consequence, as will appear hereafter.

LECTURE VIII.

The Boiler and its Appendages — Level Gauges — Feeding Apparatus — Steam Gauge — Barometer Gauge — Safety Valves — Self-regulating Damper — Edelcrantz's Valve — Furnace — Smoke-consuming Furnace — Brunton's Self-regulating Furnace — Oldham's Modification.

(67.) THE regular action of a steam-engine, as well as the economy of fuel, depends in a great degree on the construction of the boiler or apparatus for generating the steam. The boiler may be conceived as a great magazine of steam for the use of the engine; and care must be taken not only that a sufficient quantity be always ready for the supply of the machine, but also that it shall be of the proper quality; that is, that its pressure shall not exceed that which is required, nor fall short of it. Precautions should, therefore, be taken, that the production of steam should be exactly proportioned to the work to be done, and that the steam so produced shall be admitted to the cylinder in the same proportion.

To accomplish this, various contrivances, eminently remarkable for their ingenuity, have been resorted to and which we shall now proceed to describe.

(68.) Different methods have been, from time to time, suggested for indicating the level of the water in the boiler. We have already mentioned the two gauge-pipes used in the earlier steam-engines (25); and which are still in many cases continued. There are, however, some other methods which merit our attention.

A weight F (fig. 32.) half immersed in the water in the boiler, is supported by a wire, which, passing steam-tight through a small hole in the top, is connected by a flexible string or chain passing over a wheel W, with a counterpoise A, which is just sufficient to balance F, when half immersed. If F be raised above the water, A being lighter, will no longer balance it, and F will descend, pulling up A, and turning the wheel W. If, on the other hand, F be plunged deeper in the water, A will more than balance it, and will pull it up. So that the only position in which F and A will balance each other is when F is half immersed. The wheel W is so adjusted, that when two pins, placed on its rim are in the horizontal position, as in fig. 32. the water is at its proper level. Consequently it follows, that if the water rise above this level, the weight F is lifted, and A falls, so that the pins P P′ come into the position in fig. 33. If, on the other hand, the level of the water falls, F falls and A rises, so that the pins P P′ assume the position in fig. 34. Thus, in general, the position of the pins P P′ becomes an indication of the quantity of water in the boiler.

Another method is to place a glass tube (fig. 35.) with one end T entering the boiler above the proper level, and the other end T′ entering it below the proper level. It must be evident that the water in this tube will always stand at the same level as the water in the boiler; since the lower part has a free communication with that water, while the surface is submitted to the pressure of the same steam as the water in the boiler. This, and the last-mentioned gauge have the advantage of addressing the eye of the engineer at once, without any adjustment, whereas the gauge cocks (25) must be both opened, whenever the depth is to be ascertained.

These gauges, however, require the frequent attention of the engine man; and it becomes desirable either to find some more effectual means of awakening that attention, or to render the supply of the boiler, independent of any attention. In order to enforce the attention of the engine man, to replenish the boiler when partially exhausted by evaporation, a tube was sometimes inserted at the lowest level to which it was intended that the water should be permitted to fall. This tube was conducted from the boiler into the engine-house, where it terminated in a mouth-piece or whistle, so that whenever the water fell below the level at which this tube was inserted in the boiler, the steam would rush through it, and issuing with great velocity at the mouth-piece, would summon the engineer to his duty with a call that would rouse him even from sleep.

(69.) In the most effectual of these methods, the task of replenishing the boiler should still be executed by the engineer; and the utmost that the boiler itself was made to do, was to give due notice of the necessity for the supply of water. The consequence was, among other inconveniences, that the level of the water was subject to constant variation.

To remedy this, a method has been invented by which the engine is made to feed its own boiler. The pipe G′ (fig. 15.), which leads from the hot water pump H′, terminates in a small cistern C (fig. 36.), in which the water is received. In the bottom of this cistern a valve V is placed, which opens upwards, and communicates with a feed-pipe, which descends into the boiler below the level of the water in it. The stem of the valve V is connected with a lever turning on the centre D, and loaded with a weight F dipped in the water in the boiler in a manner similar to that described in fig. 32. and balanced by a counterpoise A in exactly the same way. When the level of the water in the boiler falls, the float F falls with it, and pulling down the arm E of the lever, raises the valve V, and lets the water descend into the boiler from the cistern C. When the boiler has thus been replenished, and the level raised to its former place, F will again be raised, and the valve V closed by the weight A. In practice, however, the valve V adjusts itself by means of the effect of the water on the weight F, so as to permit the water from the feeding cistern C to flow in a continued stream, just sufficient in quantity to supply the consumption from evaporation, and to maintain the level of the water in the boiler constantly the same.

By this singularly felicitous arrangement, the boiler is made to replenish itself, or, more properly speaking, it is made to receive such a supply as that it never wants replenishing, an effect which no effort of attention on the part of an engine-man could produce. But this is not the only good effect produced by this contrivance. A part of the steam which originally left the boiler, and having discharged its duty in moving the piston, was condensed and reconverted into water, and lodged by the air-pump in the hot-well (47), is here again restored to the source from which it came, bringing back all the unconsumed portion of its heat preparatory to being once more put in circulation through the machine.

The entire quantity of hot water pumped into the cistern C is not always required for the boiler. A waste-pipe may be provided for carrying off the surplus, which may be turned to any purpose for which it may be required; or it may be discharged into a cistern to cool, preparatory to being restored to the cold cistern (fig. 12.), in case water for the supply of that cistern be not sufficiently abundant.

In cities and places in which it becomes an object to prevent the waste of water, the waste-pipes, proceeding from the feed-cistern C (fig. 36.), and from the cold cistern containing the condenser and air-pump, may be conducted to a cistern A B (fig. 37.) Let C be the pipe from the feeding cistern, and D that from the cold cistern; by these pipes the waste water from both these cisterns is deposited in A B. In the bottom of A B is a valve V, opening upwards, connected with a float F. When the quantity of water collected in the cistern A B is such, that the level rises considerably, the float F is raised, and lifts the valve V, and the water flows into the main-pipe, which supplies water for working the engine. G is the cold water-pump for the supply of the cold cistern.

This arrangement for saving the water discharged from the feeding and condensing cisterns has been adopted in the printing office of the Bank of Ireland, and a very considerable waste of water is thereby prevented.

(70.) It is necessary to have a ready method of ascertaining at all times the strength of the steam which is used in working the engine. For this purpose a bent tube containing mercury is inserted into some part of the apparatus which has free communication with the steam. It is usually inserted in the *jacket* of the cylinder (44.) Let A B C (fig. 38.) be such a tube. The pressure of the steam forces the mercury down in the leg A B, and up in the leg B C. If the mercury in both legs be at exactly the same level, the pressure of the steam must be exactly equal to that of the atmosphere; because the steam pressure on the mercury in A B balances the atmospheric pressure on the mercury in B C. If, however, the level of the mercury in B C be above the level of the mercury in B A, the pressure of the steam will exceed that of the atmosphere. The excess of its pressure above that of the atmosphere may be found by observing the difference of the levels of the mercury in the tubes B C and B A; allowing a pressure of one pound on each square inch for every two inches in the difference of the levels.

If, on the contrary, the level of the mercury in B C should fall below its level in A B, the atmospheric pressure will exceed that of the steam, and the degree or quantity of the excess may be ascertained exactly in the same way.

If the tube be glass, the difference of levels of the mercury would be visible; but it is most commonly made of iron; and in order to ascertain the level, a thin wooden rod with a float, is inserted in the open end of B C; so that the portion of the stick within the tube indicates the distance of the level of the mercury from its mouth. A bulb or cistern of mercury might be substituted for the leg A B, as in the common barometer. This instrument is called the *steam-gauge.*

If the steam-gauge be used as a measure of the strength of the steam which presses on the piston, it ought to be on the same side of the throttle valve (which is regulated by the governor) as the cylinder; for if it were on the same side of the throttle valve with the boiler, it would not be affected by the changes which the steam may undergo in passing through the throttle valve, when partially closed by the agency of the governor. (61)

(71.) The force with which the piston is pressed depends on two things: 1°, the actual strength of the steam which presses on it; and 2°, on the actual strength of the vapour which resists it. For, although the vacuum produced by the method of separate condensation be much more perfect than what had been produced in the atmospheric engines, yet still some vapour of a small degree of elasticity is found to be raised from the hot water in the bottom of the condenser, before it can be extracted by the air-pump. One of these pressures is indicated by the steam-gauge already described; but still, before we can estimate the force with which the piston descends, it is necessary to ascertain the force of the vapour which remains uncondensed, and resists the motion of the piston. Another gauge, called the barometer-gauge, is provided for this purpose. A glass tube A B (fig. 39.), more than thirty inches long, and open at both ends, is placed in an upright or vertical position, having the lower end B immersed in a cistern of mercury, C. To the upper end is attached a metal tube, which communicates with the condenser, in which a constant vacuum or, rather, high degree of rarefaction is sustained. The same vacuum must, therefore, exist in the tube A B, above the level of the mercury; and the atmospheric pressure on the surface of the mercury in the cistern C will force the mercury up in the tube A B, until the column which is suspended in it is equal to the difference between the atmospheric pressure, and the pressure of the uncondensed steam. (6) The difference between the column of mercury sustained in this instrument and in the common barometer, will determine the strength of the uncondensed steam, allowing a force proportional to one pound per square inch for every two inches of mercury in the difference of the two columns. (6) In a well-constructed engine, which is in good order, there is very little difference between the altitude in the barometer gauge and the common barometer.

To compute the force with which the piston descends, thus becomes a very simple arithmetical process. First ascertain the difference of the levels of the mercury in the steam-gauge. This gives the excess of the steam pressure above the atmospheric pressure. Then find the height of the mercury in the barometer gauge. This gives the excess of the atmosperic pressure above the uncondensed steam. Hence, if these two heights be added together, we shall obtain the excess of the impelling force of the steam from the boiler on the one side of the piston above the resistance of the uncondensed steam on the other side. This will give the effective impelling force. Now, if one pound be allowed for every two inches of mercury in the two columns just mentioned, we shall have the number of pounds of impelling pressure on every square inch of the piston. Then if the number of square inches in the section of the piston be found (p. 44, note), and multiplied by the number of pounds on each square inch, the whole effective force with which it moves will be obtained.

In the computation of the power of the engine, however, all this force, thus computed, is not to be allowed as the effective working power. For it requires some force, and by no means an inconsiderable portion, to move the engine itself, even when unloaded; all this, therefore, which is spent in overcoming friction, &c. is to be left out of account, and only the balance set down as the effective working power.

From what we have stated, it appears that in order to estimate the effective force with which the piston is urged, it is necessary to refer to both the barometer and the steam-gauge. This double computation may be obviated by making one gauge serve both purposes. If the end C of the steam-gauge (fig. 38), instead of communicating with the atmosphere, were continued to the condenser, we should have the pressure of the steam acting upon the mercury in the tube B A, and the pressure of the uncondensed vapour which resists the piston acting on the mercury in the tube B C. Hence the difference of the levels of the mercury in the tubes will at once indicate the difference between the force of the steam and that of the uncondensed vapour, which is the effective force with which the piston is urged.

(71.*) To secure the boiler from accidents arising from the steam becoming too strong, a safety valve is used, similar to those described in Papin's steam-engine (40), loaded with a weight equal to the strength which the steam is intended to have above the atmospheric pressure; for it is found expedient, even in condensing engines, to use the steam of a pressure somewhat above that of the atmosphere.

Besides this valve, another of the very opposite kind is sometimes used. Upon stopping the engine, and extinguishing the fire, it is found that the steam, condensed within the boiler, produces a vacuum; so that the atmosphere, pressing on the external surface of the boiler, has a tendency to crush it. To prevent this, a safety valve is provided, which opens inwards, and which being forced open by the atmospheric pressure when a vacuum is produced within, the air rushes in, and a balance is obtained between the pressures within and without.

(72.) We have already explained the manner in which the governor regulates the supply of steam from the boiler to the cylinder, proportioning the quantity to the work to be done, and thereby sustaining an uniform motion. Since, then, the *consumption* of steam in the engine is subject to variation, owing to the various quantities of work it may have to perform, it is evident that the *production* of steam in the boiler should be subject to a proportional variation. For, otherwise, one of two effects would ensue: the boiler would either fail to supply the engine with steam, or steam would accumulate in the boiler, from being produced in too great abundance, and would escape at the safety valve, and thus be wasted. In order to vary the productions of steam in proportion to the demands of the engine, it is necessary to increase or mitigate the furnace, as production is to be augmented or diminished. To effect this by any attention on the part of the engine-man would be impossible; but a most ingenious method has been contrived, of making the boiler regulate itself in these respects. Let T (fig. 40.) be a tube inserted in the top of the boiler, and descending nearly to the bottom. The pressure of the steam on the surface of the water in the boiler forces water up in the tube T, until the difference of the levels is equal to the difference between the pressure of steam in the boiler and that of the atmosphere. A weight F, half immersed in the water in the tube, is suspended by a chain which passes over the wheels P P′, and is balanced by a metal plate D, in the same manner as the float in fig. 32. is balanced by the weight A. The plate D passes through the mouth of the flue E, as it issues finally from the boiler; so that when the plate D falls, it stops the flue, and thereby suspends the draught of air through the furnace, mitigates the fire, and diminishes the production of steam. If, on the contrary, the plate D be drawn up, the draught is increased, the fire rendered more effective, and the production of steam in the boiler stimulated. Now suppose that the boiler is producing steam faster than the engine consumes it, either because the load on the engine has been diminished, and therefore its consumption of steam proportionally diminished, or because the fire has become too intense. The consequence is, that the steam beginning to accumulate, will press upon the surface of the water in the boiler with increased force, and the water will rise in the tube T. The weight F will therefore be lifted, and the plate D will descend, stop the draught, mitigate the fire, and check the production of steam; and it will continue so to do, until the production of steam becomes exactly equal to the demands of the engine.

If, on the other hand, the production of steam be not equal to the wants of the machine, either because of the encreased load, or the insufficiency of the fire, the steam in the boiler losing its elasticity, the surface of the water rises, not sustaining a pressure sufficient to keep it at its wonted level. Therefore, the surface in the tube T falls, and the weight F falls, and the plate D rises. The draught is thus increased, by opening the flue, and the fire rendered more intense; and thus the production of steam is stimulated, until it is sufficiently rapid for the purposes of the engine. This apparatus is called the *self-acting damper.*

(73.) It has been proposed to connect this damper with a safety-valve invented by the Chevalier Edelcrantz. A small brass cylinder is fixed to the boiler, and is fitted with a piston which moves in it, without much friction, and nearly steam-tight, The cylinder is closed at top, having a hole through which the piston-rod plays; so that the piston is thus prevented from being blown out of the cylinder by the steam. The side of the cylinder is pierced with small holes opening into the air, and placed at short distances above each other. Let the piston be loaded with a weight proportional to the pressure of the steam intended to be produced. When the steam has acquired a sufficient elasticity, the piston will be lifted, and steam will escape through the first hole. If the production of steam be not too rapid, and that its pressure be not increasing, the piston will remain suspended in this manner: but if it increase, the piston will be raised above the second hole, and it will continue to rise until the escape of the steam through the holes is sufficient to render the weight of the piston a counterpoise for the steam. This safety-valve is particularly well adapted to cases where steam of an exactly uniform pressure is required; for the pressure must necessarily be always equal to the weight on the piston. Thus, suppose the section of the piston be equal to a square inch; if it be loaded with 10lbs. including its own weight, the steam which will sustain it in any position in the cylinder, whether near the bottom or top, must always be exactly equal in pressure to 10lbs. per inch. In this respect it resembles the quality already explained in the governor, and renders the pressure of the steam uniform, exactly in the same manner as the governor renders the velocity of the engine uniform.

(74.) The economy of fuel depends, in a great degree, on the construction of the furnace, independently of the effects of the arrangements we have already described.

The grate or fire-place of an ordinary furnace is placed under the boiler; and the atmospheric air passing through the ignited fuel, supplies sufficient oxygen to support a large volume of flame, which is carried by the draught into a flue which circulates twice or oftener round the boiler, and in immediate contact with it, and finally issues into the chimney. Through this flue the flame circulates, so as to act on every part of the boiler near which the flue passes; and it is not until it passes into the chimney, and frequently not until it leaves the chimney that it ceases to exist in the state of flame.

The dense black smoke which is observed to issue from the chimneys of furnaces is formed of a quantity of unconsumed fuel, and may be therefore considered as so much fuel wasted. Besides this, in large manufacturing towns, where a great number of furnaces are employed, it is found that the quantity of smoke which thus becomes diffused through the atmosphere, renders it pernicious to the health, and destructive to the comforts of the inhabitants.

These circumstances have directed the attention of engineers to the discovery of means whereby this smoke or wasted fuel may be consumed for the use of the engine itsself, or for whatever use the furnace may be applied to. The most usual method of accomplishing this, is by so arranging matters that fuel in a state of high combustion, and, therefore, producing no smoke, shall be always kept on that part of the grate which is nearest to the mouth of the flue (and which we shall call the back); by this means the smoke which arises from the imperfectly ignited fuel which is nearer to the front of the grate must pass over the surface of the red fuel, before it enters the flue, and is thereby ignited, and passes in a state of flame into the flue. A passage called the *feeding-mouth* leads to the front of the grate, and both this passage and the grate are generally inclined at a small angle to the horizon in order to facilitate the advance of the fuel according as its combustion proceeds.

When fresh fuel for feeding the boiler is first introduced, it is merely laid in the feeding mouth. Here it is exposed to the action of a part of the heat of the burning fuel on the grate, and undergoes, in some degree, the process of coking. The door of the feeding-mouth is furnished with small apertures for the admission of a stream of air, which carries the smoke evolved by the coking of the fresh fuel, over the burning fuel on the grate, by which this smoke is ignited, and becomes flame, and in this state enters the flue, and circulates round the boiler. When the furnace is to be fed, the door of the feeding mouth is opened, and the fuel which had been laid in it, and partially coked, is forced upon the front part of the grate. At first, its combustion being imperfect, but proceeding rapidly, a dense black smoke arises from it. The current of air from the open door through the feeding mouth, carries this over the vividly burning fuel, in the back part of the grate, by which the smoke being ignited, passes in a state of flame into the flue. When the furnace again requires feeding, every part of this fuel will be in a state of active combustion, and it is forced to the back part of the grate next the flue, preparatory to the introduction of more fuel from the feeding mouth.

The apertures in the door of the feeding-mouth are furnished with covers, so that the quantity of air admitted through them can be regulated by the workmen. The efficiency of these furnaces in a great degree depends on the judicious admission of the air through the feeding-mouth: for if less than the quantity necessary to support the combustion of the fuel be admitted, a part of the smoke will remain unconsumed, and if more than the proper quantity be admitted, it will defeat the effects of the fuel by cooling the boiler. If the process which we have just described be considered, it will not be difficult to perceive the total impossibility in such a furnace, of exactly regulating the draught of air, so that too much shall not pass at one time, and too little at another. When the door is open to introduce fresh fuel into the feeding-mouth, and advance that which occupied it upon the grate, the workman ceases to have any controul whatever over the draught of air; and even at other times when the door is closed, his discretion and attention cannot be depended on. The consequence is, that with these defects the proprietors of steam-engines found, that in the place of economising the fuel, the use of these furnaces entailed on them such on increased expense, that they were generally obliged to lay them aside.

(75.) Mr. Brunton of Birmingham having turned his attention to the subject, has produced a furnace which seems to be free from the objections against those we have just mentioned. The advantages of his contrivance, as stated by himself, are as follow:

"First, I put the coal upon the grate by small quantities, and at very short intervals, say every two or three seconds: 2ndly, I so dispose of the coals upon the grate, that the smoke evolved must pass over that part of the grate upon which the coal is in full combustion, and is thereby consumed; 3rdly, as the introduction of the coal is uniform in short spaces of time, the introduction of the air is also uniform, and requires no attention from the fireman.

"As it respects economy: 1st, the coal is put upon the fire by an apparatus driven by the engine, and so contrived that the quantity of coal is proportioned to the quantity of work which the engine is performing, and the quantity of air admitted to consume the smoke is regulated in the same manner; 2ndly, the fire door is never opened, excepting to clean the fire;

the boiler of course is not exposed to that continual irregularity of temperature which is unadvoidable in the common furnace, and which is found exceedingly injurious to boilers; 3rdly, the only attention required is to fill the coal receiver, every two or three hours, and clean the fire when necessary; 4thly, the coal is more completely consumed than by the common furnace, as all the effect of what is termed stirring up the fire (by which no inconsiderable quantity of coal is passed into the ash-pit) is attained without moving the coal upon the grate."

The fire-place is a circular grate placed on a vertical shaft in an horizontal position. It is capable of revolving, and is made to do so by the vertical shaft, which is turned by wheel-work, which is worked by the engine itself; or this shaft or spindle may be turned by a water-wheel, on which a stream of water is allowed to flow from a reservoir, into which it is pumped by the power of the engine; and by regulating the quantity of water in the stream, the grate may be made to revolve with a greater or lesser speed. In that part of the boiler which is over the grate, there is an aperture in which is placed a hopper, through which fuel is let down upon the grate at the rate of any quantity per minute that may be required. The apparatus which admits the coals through this hopper is worked by the engine also, and, by the same means as the grate, is turned so that the grate revolves with a speed proportional to the rapidity with which the fuel is admitted through the hopper, and by this ingenious arrangement, the fuel falls equally thick upon the grate.

The supply of water which turns the wheel which works the grate and the machinery in the hopper, is regulated by a cock connected with the self-regulating damper, so that when the steam is being produced too fast, the supply of water will be diminished; and by that means the supply of fuel to the grate will be diminished, and the grate will revolve less rapidly, and when the steam is being produced too slowly for the demands of the engine, the contrary effects take place. In this way the fuel which is introduced into the furnace is exactly proportioned to the work which the engine has to perform. The hopper may be made large enough to hold coals for a day's work, so that the furnace requires no other attendance than to deposit coals in the hopper each morning.

The coals are let down from the hopper on the grate at that part which is most remote from the flue, and as they descend in very small quantities at a time, they are almost immediately ignited. But until their ignition is complete, a smoke will arise, which, passing to the flue over the vividly burning fuel, will be ignited. Air is admitted through proper apertures, and its quantity regulated by the damper in the same manner as the supply of fuel.

The superiority of this beautiful invention over the common smoke-consuming furnaces is very striking. Its principle of self-adjustment as to the supply of coals and atmospheric air, and the proportioning of these to the quantity of work to be performed by the engine, not only independent of human labor, but with a greater degree of accuracy than any human skill or attention could possibly effect, produces an extensive saving of expense, both in fuel and labor.

Mr. Partington states that the effect of the self-regulating furnace, as compared with the common furnace, has been ascertained by direct experiment at the Old Union Mill, Birmingham, and at the distillery of Messrs. Liptrap and Smith, Whitechapel, London. The results of these experiments were as follow :

At the Old Union Mill, nine day's experiment—
Common furnace consumed.... 465 cwt.
Regulating furnace .... 290 cwt.

Saving........ 175 cwt.

At the Whitechapel distillery, eighteen days' experiment —
Common furnace consumed .... 284 cwt.
Regulating furnace .... 194 cwt.

Saving........ 90 cwt.

From which it appears that the saving in the first case is about 37 per cent. and in the second but very little less.

(76.) Mr. Oldham, engineer to the Bank of Ireland, has proposed another modification of the self-regulating furnace, which seems to possess several advantages, and evinces considerable ingenuity.

He uses a slightly inclined grate, at the back or lower end of which is the flue, and at the front or higher end, the hopper for admitting the coals. In the bottom or narrow end of the hopper is a moveable shelf worked by the engine. Upon drawing back this shelf, a small quantity of fuel is allowed to descend upon a fixed shelf under it; and upon the return of the moveable shelf this fuel is protruded forward upon the grate. Every alternate bar of the grate is fixed, but the intermediate ones are connected with levers, by which they are moved alternately up and down.* The effect is, that the coals upon the bars are continually stirred, and gradually advanced by their own weight from the front of the grate where they fall from the hopper, to the back, where they are deposited in the ash-pit. By the shape and construction of the bars, the air is conducted upwards between them, and rushes through the burning fuel, so as to act, as Mr. Oldham states, in the manner of a blow-pipe, and the entire surface of the fire presents a sheet of flame.

We cannot fail to be struck with the beauty of all these contrivances, by which the engine is made to regulate itself, and to supply its own wants. It is, in fact, all but alive. It was observed by Belidor, long before the steam-engine reached the perfection which it has now acquired, that it strongly resembled an animal, and that no mere work of man ever approached so near to actual *life*. Heat is the principle of its existence. The boiler acts the part of the heart from which its vivifying fluid rushes copiously through all the tubes, where having discharged the various functions of life, and deposited its heat in the proper places, returns again to the source it sprung from, to be duly prepared for another circulation. The healthfulness of its action is indicated by the regularity of its pulsations; it procures its own food by its own labor; it selects those parts which are fit for its support, both as to quantity and quality, and has its natural evacuations, by which all the useless and unnutritious parts are discharged. It frequently cures its own diseases, and corrects the irregularity of its own actions, exerting something like physical and moral faculties. Without designing to carry on the analogy, Mr. Farey, in speaking of the variations incident to the work performed by different steam-engines, states some further particulars in which it may be curiously extended. "We must observe," says he, "that the variation in the performance of different steam-engines, which are constructed on the same principle, working under the same advantages, is the same as would be found in the produce of the labor of so many different horses or other animals when compared with their consumption of food; for the effects of different steam-engines will vary as much from small differences in the proportion of their parts, as the strength of animals from the vigor of their constitutions; and again there will be as great differences in the performance of the same engine when in good and bad order, from all the parts being tight and well oiled, so as to move with little friction, as there is in the labor of an animal from his being in good or bad health or excessively fatigued; but in all these cases there will be a maximum which cannot be exceeded, and an average which we ought to expect to obtain."

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* Mr. Brunton used moveable bars in a furnace constructed by him before he adopted the horizontal revolving grate. That plan, however, does not appear to have been as successful as the latter, as he has abandoned it. Mr. Oldham states that his furnace has been in use for three years without any appearance of derangement in the mechanism, and with a considerable saving of fuel.

LECTURE IX.

Double Cylinder Engines—Hornblower's Engine—Woolf's Engine—Cartwright's Engine.

(77.) THE expansive property of steam, of which Watt availed himself in his single engine by cutting off the supply of steam before the descent of the piston was completed, was applied in a peculiar manner by an engineer named Hornblower, about the year 1781, and at a later period by Woolf. Hornblower was the first who conceived the idea of working an engine with two cylinders of different sizes, by allowing the steam to flow freely from the boiler until it fills the smaller cylinder, and then permitting it to expand into the greater one, employing it thus to press down two pistons in the manner which we shall presently describe. The condensing apparatus of Hornblower, as well as the other appendages of the engine, do not differ materially from those of Watt; so that it will be sufficient for our present purpose, to explain the manner in which the steam is made to act in moving the piston.

Let c, fig. 41, be the centre of the great working beam carrying two arch heads, on which the chains of the piston rods play. The distances of these arch heads from the centre C must be in the same proportion as the length of the cylinders, in order that the same play of the beam may correspond to the plays of both pistons. Let F be the steam-pipe from the boiler, and G be a valve to admit the steam above the lesser piston. H is a tube by which a communication may be opened by the valve I between the top and bottom of the lesser cylinder B. K is a tube communicating by the valve L between the bottom of the lesser cylinder B, and the top of the greater cylinder A. M is a tube communicating by the valve N between the top and bottom of the greater cylinder A; and P a tube leading to the condenser by the exhausting valve O.

At the commencement of the operation, suppose all the valves opened, and steam allowed to flow through the entire engine until the air be completely expelled, and then let all the valves be closed. To start the engine, let the exhausting valve O, and the steam valves F and L be opened as in fig. 41. The steam will flow freely from the boiler, and press upon the lesser piston, and at the same time the steam below the greater piston will flow into the condenser, leaving a vacuum in the greater cylinder. The valve L being opened, the steam which is under the piston in the lesser cylinder will flow through K, and press on the greater piston, which having a vacuum beneath it, will consequently descend. At the commencement of the motion, the lesser piston is as much resisted by the steam below it, as it is urged by the steam above it; but after a part of the descent has been effected, the steam below the lesser piston passing into the greater, expands into an increased space, and therefore loses its elastic force proportionally. The steam above the lesser piston retaining its full force by having a free communication with the boiler by the valve G, the lesser piston will be urged by a force equal to the excess of the pressure of this steam above the diminished pressure of the expanded steam below it. As the pistons descend, the steam which is between them is continually increasing in its bulk, and therefore decreasing in its pressure, from whence it follows that the force which resists the lesser piston is continually decreasing, while that which presses it down remains the same, and therefore the effective force which impels it, must be continually increasing.

On the other hand, the force which urges the greater piston is continually decreasing, since there is a vacuum below it, and the steam which presses it is continually expanding into an increased bulk.

Impelled in this way, let us suppose the pistons to have arrived at the bottoms of the cylinders as in fig. 42, and let the valves F, L and O, be closed, and the valves I and N opened. No steam is allowed to flow from the boiler F being closed, nor any allowed to pass into the condenser, since O is closed and all communication between the cylinders is stopped by closing L. By opening the valve I, a free communication is made between the top and bottom of the lesser piston through the tube H, so that the steam which presses above the lesser piston will exert the same pressure below it, and the piston is in a state of indifference. In the same manner the valve N being open, a free communication is made between the top and bottom of the greater piston, and the steam circulates above and below the piston, and leaves it free to rise. A counterpoise attached to the pump-rods in this case, draws up the piston as in Watt's single engine. And when they arrive at the top, the valves I and N are closed and F, L and O opened, and the next descent of the pistons is produced in the manner already described, and so the process is continued.

The valves are worked by the engine itself, by means similar to some of those already described. By computation, we find the power of this engine to be nearly the same as a similar engine on Watt's expansive principle. It does not however appear, that any adequate advantage was to be gained by this modification of the principle, since no engines of this construction are now made.

(78.) The use of two cylinders was revived by *Arthur Woolf*, in 1804, who, in this and the succeeding year, obtained patents for the application of steam raised under an high pressure to double cylinder engines. The specification of his patent states, that he has proved by experiment, that steam raised under a safety-valve loaded with any given number of pounds upon the square inch, will if allowed to expand into as many times its bulk as there are pounds of pressure on the square inch, have a pressure equal to that of the atmosphere. Thus, if the safety-valve be loaded with four pounds, on the square inch, the steam, after expanding into four times its bulk, will have the atmospheric pressure. If it be loaded with 5, 6, or 10 lbs. on the square inch, it will have the atmospheric pressure when it has expanded into 5, 6, or 10 times its bulk, and so on. It is, however, understood in this case, that the vessel into which it is thus allowed to expand, must have the same temperature as the steam before it expands.

Mr. Woolf's method of availing himself of the fact, which he thus alleges himself to have discovered, is as follows:

Two cylinders are provided: a larger, A, (fig. 43); and a smaller, B, such, that A shall be as many times larger than B, as there are pounds weight avoirdupoise placed upon the safety-valve. Valves C C′ are placed at each end of the lesser cylinder, in tubes, communicating with the boiler, so as to admit steam on each side of the lesser piston, and cut it off at pleasure. A tube, D′, forms a communication between the upper end of the lesser, and lower end of the greater cylinder, and which communication is opened and closed at pleasure by the valve E′. In like manner, the tube D forms a communication between the lower end of the lesser cylinder, and the upper end of the greater, which may be opened and closed by the valve E. The top and bottom of the greater cylinder communicate with the condenser by valves F′ F.

Let us suppose that the air is blown from the engine in the usual way, and all the valves closed, and the engine ready to start, the pistons being at the top of the cylinders. Open the valves C, E and F. The steam which occupies the greater cylinder below the piston, will now pass into the condenser through F, leaving a vacuum below the piston. The steam which is in the lesser cylinder below the piston will pass through D and the open valve E, and will press down the greater piston. The steam from the boiler will flow in at C, and press on the lesser piston. At first the whole motion will proceed from the pressure upon the greater piston, since the steam both above and below the lesser piston, has the same pressure. But as the pistons descend, the steam below the less passing into the greater cylinder, expands into a greater space, and consequently exerts a diminished pressure, and, therefore, the steam on the other side exerting an undiminished pressure, acquires an impelling force exactly equal to the pressure lost in the expansion of the steam between the two pistons. Thus both pistons will be pressed to the bottoms of their respective cylinders. It will be observed that in the descent the greater piston is urged by a continual decreasing force, while the lesser is urged by continually increasing force.

Upon the arrival of the pistons at the bottoms of the cylinders, let the valves C, E, F be closed, and C′, E′, F′ be opened, as in fig. 44. The steam which is above the greater piston now flows through F′ into the condenser, leaving the space above the piston a vacuum. The steam which is above the lesser piston passes through E′ and D′ below the greater, while steam from the boiler is admitted through C′ below the lesser piston. The pressure of the steam entering through E′ below the greater piston, pressing on it against the vacuum above it, commences the ascent. In the mean time the steam above the lesser piston passing into the enlarged space of the greater cylinder, loses gradually its elastic force, so that the steam entering from the boiler at c′ becomes in part effective, and the ascent is completed under exactly the same circumstances as the descent, and in this way the process is continued.

It is evident that the valves may be easily worked by the mechanism of the engine itself.

In this arrangement the pistons ascend and descend together, and their rods must consequently be attached to the beam at the same side of the centre. It is sometimes desirable that they should act on different sides of the centre of the beam, and consequently that one should ascend while the other descends. It is easy to arrange the valves so as to effect this. In fig. 45, the lesser piston is at the bottom of the cylinder, and the greater at the top. On opening the valves C,′ E′ F′, a vacuum is produced below the greater piston, and steam flows from the lesser cylinder through E′ *above* the greater piston, and presses it down. At the same time steam being admitted from the boiler through c′ below the lesser piston, forces it up against the diminishing force of the steam above it, which expands into the greater cylinder. Thus as the greater piston descends the lesser ascends. When each has traversed its cylinder, the valves c′, E′, F′ being closed and C, E, F opened, the lesser piston will descend, and the greater ascend, and so on.

Woolf's engine differs from that of Hornblower in using steam of an high pressure. and in being a double-acting engine. It is stated by Mr. Farey that some of these engines, which have been erected in

Cornwall, perform with an evident saving of fuel. It does not, however, appear that they have to any extent superseded the steam-engines of Watt. There are some peculiarities in the boiler used by Woolf for generating steam of the high pressure required for his engines, but these engines are not in sufficiently general use to induce us to enter further upon the subject here.

(79.) In 1797 a patent was granted to the *Rev. Mr. Cartwright,* a gentleman well known for other mechanical inventions, for some improvements in the steam-engine. His contrivance is at once so elegant and simple, that although it has not obtained very general use, yet we cannot here pass it over without notice.

The steam-pipe from the boiler is represented cut off at B (fig. 46); T is a spindle-valve for admitting steam above the piston, and R is a spindle-valve in the piston; D is a curved pipe forming a communication between the cylinder and the condenser, which is of very peculiar construction. Cartwright proposed effecting the condensation without a jet, by exposing the steam to contact with a very large quantity of cold surface. For this purpose, he formed his condenser, by placing two cylinders nearly equal in size, one within the other, allowing the water of the cold cistern in which they were placed to flow through the inner cylinder, and to surround the outer one. Thus the thin space between the two cylinders formed the condenser.

The air-pump is placed immediately under the cylinder, and the continuation of the piston-rod works its piston, which is solid and without a valve: F is the pipe from the condenser to the air-pump, through which the condensed steam is drawn off through the valve G on the ascent of the piston, and on the descent, this is forced through a tube into a hot well, H, for the purpose of feeding the boiler through the feed-pipe I. In the top of the hot well H is a valve which opens inwards, and is kept closed by a ball floating on the surface of the liquid. The pressure of the condensed air above the surface of the liquid in H forces it through I into the boiler. When the air accumulates in too great a degree in H, the surface of the liquid is pressed so low that the ball falls and opens the valve, and allows it to escape. The air in H is that which is pumped from the condenser with the liquid, and which was disengaged from it.

Let us suppose the piston at the top of the cylinder; it strikes the tail of the valve T, and raises it, while the stem of the piston-valve R strikes the top of the cylinder, and is pressed into its seat. A free communication is at the same time open between the cylinder, below the piston and the condenser, through the tube D. The pressure of the steam thus admitted above the piston, acting against the vacuum below it, will cause its descent. On arriving at the bottom of the cylinder, the tail of the piston-valve R will strike the bottom, and it will be lifted from its seat, so that a communication will be opened through it with the condenser. At the same moment, a projecting spring, K, attached to the piston-rod, strikes the stem of the steam-valve T, and presses it into its seat. Thus, while the further admission of steam is cut off, the steam above the piston flows into the condenser, and the piston being relieved from all pressure, is drawn up by the momentum of the fly-wheel, which continues the motion it received from the descending force. On the arrival of the piston again at the top of the cylinder, the valve T is opened and R closed, and the piston descends as before, and so the process is continued.

The mechanism by which motion is communicated from the piston to the fly-wheel is peculiarly elegant. On the axis of the fly-wheel is a small wheel with teeth, which work in the teeth of another larger wheel L. This wheel is turned by a crank, which is worked by a cross-piece attached to the end of the piston-rod. Another equal toothed wheel M, is turned by a crank, which is worked by the other end of the cross-arm attached to the piston-rod.

One of the peculiarities of this engine, is, that the liquid which is used for the production of steam in the boiler circulates through the machine without either diminution or admixture with any other fluid, so that the boiler never wants more feeding than what can be supplied from the hot-well H. This circumstance forms a most important feature in the machine, as it allows of ardent spirits being used in the boiler instead of water, which since they boil at low heats, promised a saving of half the fuel. The inventor even proposed, that the engine should be used as a still, as well as a mechanical power, in which case, the whole of the fuel would be saved.

In this engine, the ordinary method of rendering the piston steam-tight, by oil or melted wax, or tallow poured upon it, could not be applied, since the steam above the piston must always have a free passage through the piston-valve R. The ingenious inventor therefore contrived a method of making the piston steam-tight in the cylinder, without oil or stuffing, and his method has since been adopted with success in Woolf's engines.

A ring of metal is ground into the cylinder, so as to fit it perfectly, and is then cut into four equal segments. The inner surface of this ring being slightly conical, another ring is ground into it, so as to fit it perfectly, and this is also cut into four segments, and one is placed within the other, but in such a manner, that the joints or divisions do not coincide. The arrangement of the two rings is represented in fig. 47. Within the inner ring are placed four springs which press the pieces outward against the sides of the cylinder, and are represented in the diagram. Four pairs of these rings are placed one over another, so that their joints do not coincide, and the whole is screwed together by plates placed at top and bottom. A vertical section of the piston is given in fig. 48.

One of the advantages of this piston is, that the longer it is worked, the more accurately it fits the cylinder, so that, as the machine wears it improves.

LECTURE X.

LOCOMOTIVE ENGINES ON RAILWAYS.

High pressure Engines — Leupold's Engine — Trevithick and Vivian — Adhesion with Rail-road — Blenkinsop's Patent — Chapman's Improvement — Walking Engine — Stephenson's first Engines — His Improvements — Liverpool and Manchester Railway Company — Their preliminary Proceedings — The great Competition of 1829 — The Rocket—The Sans-pareil—The Novelty—Result of the Competition— Qualities of the Rocket — Successive Improvements — Present Performance on the Railway — Defects of the present Engines— Inclined Planes on Railways — Methods of surmounting them —Inconvenience of the great Power of Engines — Account of Receipts and Expenses on the Liverpool Railway — Its present Profits and future Prospects — Observations on its Management — Projected Railways — Steam Power compared with Horse Power — Rail Roads compared with Canals — Liverpool and Manchester Canal.

(80.) In the various modifications of the steam-engine which we have hitherto considered, the pressure introduced on one side of the piston derives its efficacy either wholly or partially from the vacuum produced by condensation on the other side. This always requires a condensing apparatus, and a constant and abundant supply of cold water. An engine of this kind must, therefore, necessarily have considerable dimensions and weight, and is inapplicable to uses in which a small and light machine only is admissible. If the condensing apparatus be dispensed with, the piston will always be resisted by a force equal to the atmospheric pressure, and the only part of the steam pressure which will be available as a moving power, is that part by which it exceeds the pressure of the atmosphere. Hence, in engines which do not work by condensation, steam of a much higher pressure than that of the atmosphere is indispensably necessary, and such engines are therefore called *high pressure engines.*

We are not, however, to understand that every engine, in which steam is used of a pressure exceeding that of the atmosphere, is what is meant by an *high pressure engine;* for in the ordinary engines in common use, constructed on Watt's principle, the safety-valve is loaded with from 3 to 5 lbs. on the square inch; and in Woolf's engines, the steam is produced under a pressure of 40 lbs. on the square inch. These would therefore be more properly called *condensing-engines* than *low pressure engines;* a term utterly inapplicable to those of Woolf. In fact, by *high pressure engines* is meant engines in which no vacuum is produced, and, therefore, in which the piston works against a pressure equal to that of the atmosphere.

In these engines, the whole of the condensing apparatus, *viz.* the cold water cistern, condenser, air-pump, cold water pump, &c. are dispensed with, and nothing is retained except the boiler, cylinder, piston, and valves. Consequently, such an engine is small, light, and cheap. It is portable also, and may be moved, if necessary, along with its load, and is therefore well adapted to locomotive purposes.

(81.) High pressure engines were one of the earliest modifications of the steam-engine. The contrivance, which is obscurely described in the article already quoted (23), from the Century of Inventions, is an high-pressure engine; for the power there alluded to is the elastic force of steam working against the atmospheric pressure. *Newcomen*, in 1705, applied the working-beam, cylinder, and piston to the atmospheric engine; and *Leupold*, about 1720, combined the working-beam and cylinder with the high pressure principle, and produced the earliest high-pressure engine worked by a cylinder and piston. The following is a description of *Leupold's* engine: —

A (fig. 49.) is the boiler, with the furnace beneath it; C C′ are two cylinders with solid pistons, P P′, connected with the working-beams B B′, to which are attached the pump-rods R R′ of two forcing-pumps, F F′, which communicate with a great force-pipe S; G is a *four-way cock* (66) already described. In the position in which it stands in the figure, the steam is issuing from below the piston P into the atmosphere, and the piston is descending by its own weight; steam from the boiler is at the same time pressing up the piston P′, with a force equal to the difference between the pressure of the steam and that of the atmosphere. Thus the piston R of the forcing-pump is being drawn up, and the piston P′ is forcing the piston R′ down, and thereby driving water into the force-pipe S. On the arrival of the piston P at the bottom of the cylinder C, and P′ at the top of the cylinder C′, the position of the cock is changed as represented in fig. 50. The steam, which has just pressed up the piston P′, is allowed to escape into the atmosphere, while the steam, passing from the boiler below the piston P, presses it up, and thus P ascends by the steam pressure, and P′ descends by its own weight. By these means the piston R is forced down, driving before it the water in the pump-cylinder into the force-pipe S, and the piston R′ is drawn up to allow the other pump-cylinder to be re-filled; and so the process is continued.

A valve is placed in the bottom of the force-pipes, to prevent the water which has been driven into it from returning. This valve opens upwards; and, consequently, the weight of the water pressing upon it only keeps it more effectually closed. On each descent of the piston, the pressure transmitted to the valve acting upwards being greater than the weight of the water resting upon it, forces it open, and an increased quantity of water is introduced.

(82.) From the date of the improvement of Watt until the commencement of the present century, high-pressure engines were altogether neglected in these countries. In the year 1802, Messrs. *Trevithic* and *Vivian* constructed the first high-pressure engine which was ever brought into extensive practical use in this kingdom. A section of this machine, made by a vertical plane, is represented in fig. 51.

The boiler A B is a cylinder with flat circular ends. The fire-place is constructed in the following manner: — a tube enters the cylindrical boiler at one end; and, proceeding onwards, near the other extremity, is turned and recurved, so as to be carried back parallel to the direction in which it entered. It is thus conducted out of the boiler, at another part of the same end at which it entered. One of the ends of this tube communicates with the chimney E, which is carried upwards, as represented in the figure. The other mouth is furnished with a door; and in it is placed the grate, which is formed of horizontal bars, dividing the tube into two parts; the upper part forming the fire-place, and the lower the ash-pit. The fuel is maintained in a state of combustion, on the bars, in that part of the tube represented at C D; and the flame is carried by the draft of the chimney round the curved flue, and issues at E into the chimney. The flame is thus conducted through the water, so as to expose the latter to as much heat as possible.

A section of the cylinder is represented at F, immersed in the boiler, except a few inches of the upper end, where the four-way cock G is placed for regulating the admission of the steam. A tube is represented at H, which leads from this four-way cock into the chimney; so that the waste steam, after working the piston, is carried off through this tube, and passes into the chimney. The upper end of the piston-rod is furnished with a cross-bar, which is placed in a direction at right angles to the length of the boiler, and also to the piston-rod. This bar is guided in its motion by sliding on two iron perpendicular rods fixed to the sides of the boiler, and parallel to each other. To the ends of this cross-bar are joined two connecting-rods, the lower ends of which work two cranks fixed on an axis extending across and beneath the boiler, and immediately under the centre of the cylinder. This axis is sustained in bearings formed in the legs which support the boiler, and upon its extremity is fixed the fly-wheel as represented at B. A large-toothed wheel is placed on this axis; which, being turned with the cranked axle, communicates motion to other wheels; and, through them, to any machinery which the engine may be applied to move.

As the four-way cock is represented in the figure, the steam passes from the boiler through the curved passage G above the piston, while the steam below the piston is carried off through a tube which does not appear in the figure, by which it is conducted to the tube H, and thence to the chimney. The steam, therefore, which passes above the piston presses it downwards; while the pressure upwards does not exceed that of the atmosphere. The piston will, therefore, descend with a force depending on the excess of the pressure of the steam produced in the boiler above the atmospheric pressure. When the piston has arrived at the bottom of the cylinder, the cock is made to assume the position represented in the figure 52. This effect is produced by the motion of the piston-rod. The steam now passes from above the piston, through the tube H, into the chimney, while the steam from the boiler is conducted through another tube below the piston. The pressure above the piston, in this case, does not exceed that of the atmosphere; while the pressure below it will be that of the steam in the boiler. The piston will, therefore, ascend with the difference of these pressures. On the arrival of the piston at the top of the cylinder, the four-way cock is again turned to the position represented in fig. 51., and the piston again descends; and in the same manner the process is continued. A safety-valve is placed on the boiler at V, loaded with a weight, W, proportionate to the strength of the steam with which it is proposed to work.

In the engines now described, this valve was frequently loaded at the rate of from 60 to 80 lbs. on the square inch. As the boilers of high-pressure engines were considered more liable to accidents from bursting than those in which steam of a lower pressure was used, greater precautions were taken against such effects. A second safety-valve was provided, which was not left in the power of the engine-man. By this means he had a power to diminish the pressure of the steam, but could not increase it beyond the limit determined by the valve which was removed from his interference. The greatest cause of danger, however, arose from the water in the boiler being consumed by evaporation faster than it was supplied; and therefore falling below the level of the tube containing the furnace. To guard against accidents arising from this circumstance, a hole was bored in the boiler, at a certain depth, below which the water should not be allowed to fall; and in this hole a plug of metal was soldered with lead, or with some other metal, which would fuse at that temperature which would expose the boiler to danger. Thus, in the event of the water being exhausted, so that its level would fall below the plug, the heat of the furnace would immediately melt the solder, and the plug would fall out, affording a vent for the steam, without allowing the boiler to burst. The mercurial steam-gage, already described, was also used as an additional security. When the force of the steam exceeded the length of the column of mercury which the tube would contain, the mercury would be blown out, and the tube would give vent to the steam. The water by which the boiler was replenished was forced into it by a pump worked by the engine. In order to economise the heat, this water was contained in a tube T, which surrounded the pipe H. As the waste steam, after working the piston, passed off through H, it imparted a portion of its heat to the water contained in the tube T; which was thus warmed to a certain temperature before it was forced into the boiler by the pump. Thus a part of the heat, which was originally carried from the boiler in the form of steam, was returned again to the boiler with the water with which it was fed.

It is evident that engines constructed in this manner may be applied to all the purposes to which the condensing engines are applicable.

(83.) Two years after the date of the patent of this engine, its inventor constructed a machine of the same kind for the purpose of moving carriages on railroads; and applied it successfully, in the year 1804, on the railroad at Merthyr Tydvil, in South Wales. It was in principle the same as that already described. The cylinder, however, was in a horizontal position, the piston-rod working in the direction of the line of road; the extremity of the piston-rod, by means of a connecting rod, worked cranks placed on the axletree, on which were fixed two cogged wheels; these worked in others, by which their motion was communicated finally to cogged wheels fixed on the axle of the hind wheels of the carriage, and by which this axle was kept in a state of revolution. The hind wheels being fixed on the axletree, and turning with it, were caused likewise to revolve; and so long as the weight of the carriage did not exceed that which the friction of the road was capable of propelling, the carriage would thus be moved forwards. On this axle was placed a fly-wheel to continue the rotatory motion at the termination of each stroke. The fore wheels are described as being capable of turning like the fore wheels of a carriage, so as to guide the vehicle. The projectors appear to have contemplated, in the first instance, the use of this carriage on turnpike roads; but that notion seems to have been abandoned, and its use was only adopted on the railroad before mentioned. On the occasion of its first trial, it drew after it as many carriages as contained 10 tons of iron a distance of nine miles; which stage it performed without any fresh supply of water, and travelled at the rate of five miles an hour.

From this period, travelling steam-engines (or, as they are since called, locomotive engines,) became a favourite speculation with engineers; and they have, for the last 28 years, undergone considerable modifications and improvements, the effects of which are to be seen in the intercourse by railway carried on between Liverpool and Manchester.

(84.) It is a singular fact in the history of this invention, that a considerable time and a great quantity of ingenuity were vainly expended in attempting to overcome a difficulty, which, in the end, turned out to be purely imaginary. To comprehend distinctly the manner in which a carriage is propelled by steam, let us suppose that the wheels of a common carriage are locked, the carriage being placed on a level road. Let the force be now ascertained experimentally which would be necessary to drag the carriage along the road, the wheels slipping or scraping along the surface. Again, suppose the wheels disengaged, so as to be at liberty to revolve; let another carriage be now attached to the first, behind it, so that the one cannot proceed without dragging the other after it; let this other carriage be loaded, so that its own weight, together with that of its load, shall be equal to the force which was found necessary to drag the first carriage when the wheels were locked. If the wheels of the first carriage be now turned by force applied at their spokes or rims, it will be found that they will revolve without causing the carriage to advance; but that they will scrape or slip on the road. This will be obvious on the least consideration; for the load which is now attached to the carriage, so as to resist its progressive motion, is exactly equal to that which in the former case was sufficient to move the carriage, the wheels being locked. In each case, the resistance to be overcome is the friction of the wheels of the first carriage with the road; and, consequently, as in the former case, it was unable to overcome this resistance; so, in the latter, this resistance is insufficient to overcome the same load. But if the weight of the second carriage be diminished, so as to be less than that which would be necessary to move the first carriage, the wheels being locked, then, on causing the wheels of the first carriage to revolve, by any force applied on their spokes or rims, the first carriage will necessarily advance, drawing the second after it. This must obviously happen;

because the weight of the second carriage is less than that which is necessary to overcome the resistance of friction between the wheels of the first carriage and the road.

An experiment of this kind will obviously determine the load which any carriage is capable of drawing after it, by the force applied on the wheels, to cause them to revolve; and the amount of this load will depend partly on the quantity of adhesion which subsists between the wheels and the road, and partly on the evenness of the road itself: the more smooth and even the road is, and the greater the quantity of friction or adhesion there is between the wheels and the road, and the less will be the obstructions to the rolling motion; for both these reasons the greater will be the load which a given carriage is capable of drawing after it when propelled in this way.

A notion was impressed on the minds of the speculators in locomotive engines, for many years, that the friction or adhesion between the wheels and the road upon which the propelling power of a machine of this kind must depend, was of very small amount; and that, in every practical case, the wheels, instead of causing the carriage to advance, would slip or slide on the road; or that, if the carriage advanced, still that a portion of the moving power would be lost by this slipping or sliding. It is singular that it should never have occurred to these ingenious persons to ascertain by experiment the actual quantity of adhesion in any particular case between the wheels and the road: had they done so, we should probably have found at this time locomotive engines in a much more forward state of perfection than that to which they have attained.

To remedy this imaginary difficulty, Messrs. *Trevithick* and *Vivian* proposed to make the external rims of the wheels rough and uneven, by surrounding them with projecting heads of nails or bolts, or by cutting transverse grooves on them. They proposed, in cases where considerable elevations were to be ascended, to cause claws or nails to project from the surface during the ascent, so as to take hold of the road.

In seven years after the construction of the first locomotive engine by these engineers, another locomotive engine was constructed by Mr. *Blinkensop*, of Middleton Colliery, near Leeds. He obtained a patent, in 1811, for the application of a rack-rail. The railroad thus, instead of being composed of smooth bars of iron, presented a line of projecting teeth, like those of a cog-wheel, which stretched along the entire distance to be travelled. The wheels on which the engine rolled were furnished with corresponding teeth, which worked in the teeth of the railroad; and, in this way, produced a progressive motion in the carriage.

The next contrivance for overcoming this fictitious difficulty was that of Messrs. *Chapman*, who, in the year 1812, obtained a patent for working a locomotive engine by a chain extending along the middle of the line of railroad, from the one end to the other. This chain was passed once round a grooved wheel under the centre of the carriage; so that, when this grooved wheel was turned by the engine, the chain being incapable of slipping upon it, the carriage was consequently advanced on the road. In order to prevent the strain from acting on the whole length of the chain, its links were made to fall upon upright forks placed at certain intervals, which between those intervals sustained the tension of the chain produced by the engine. Friction-rollers were used to press the chain into the groove of the wheel, so as to prevent it from slipping. This contrivance was soon abandoned, for the very obvious reason that a prodigious loss of force was incurred by the friction of the chain.

(85). The following year, 1813, produced a contrivance, of singular ingenuity, for overcoming the supposed difficulty arising from the want of adhesion between the wheels and the road. This was no other than a pair of mechanical legs and feet, which were made to walk and propel in a manner somewhat resembling the feet of an animal.

A sketch of these propellers is given in fig. 53. A is the car-

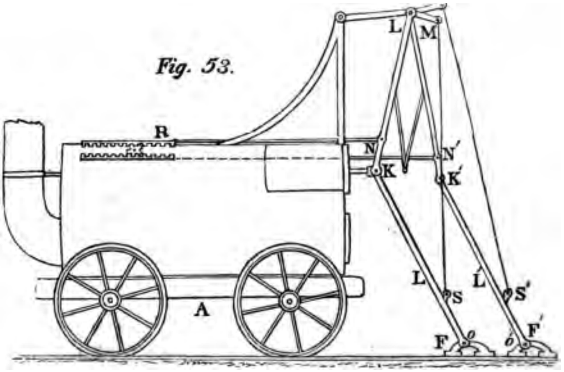

Fig. 53.

riage moving on the railroad, L and L′ are the legs, F and F′ the feet. The foot F has a joint at O, which corresponds to the ankle; another joint is placed at K, which corresponds to the knee; and a third is placed at L, which corresponds to the hip. Similar joints are placed at the corresponding letters in the other leg. The knee-joint K is attached to the end of the piston of the cylinder. When the piston, which is horizontal, is pressed outwards, the leg L presses the foot F against the ground, and the resistance forces the carriage A onwards. As the carriage proceeds, the angle K at the knee becomes larger, so that the leg and thigh take a straighter position; and this continues until the piston has reached the end of its stroke. At the hip L there is a short lever, L M, the extremity of which is connected by a cord or chain with a point, S, placed near the shin of the leg. When the piston is pressed into the cylinder, the knee, K, is drawn towards the engine, and the cord, M S, is made to lift the foot, F, from the ground; to which it does not return until the piston has arrived at the extremity of the cylinder. On the piston being again driven out of the cylinder, the foot, F, being placed on the road, is pressed backwards by the force of the piston-rod at K; but the friction of the ground preventing its backward motion, the re-action causes the engine to advance: and in the same manner this process is continued.

Attached to the thigh, at N, above the knee, by a joint, is a horizontal rod, N R, which works a rack, R. This rack has beneath it a cog-wheel. This cog-wheel acts in another rack below it. By these means, when the knee K is driven *from* the engine, the rack R is moved *backwards;* but the cog-wheel, acting on the other rack beneath it, will move the latter *in the contrary direction.* The rack R being then moved *in the same direction with the knee,* K, it follows that the other rack will always be moved *in a contrary direction.* The lower rack is connected by another horizontal rod with the thigh of the leg, L F′, immediately above the knee, at N′. When the piston is forced *inwards,* the knee, K′, will thus be forced *backwards;* and when the piston is forced *outwards,* the knee, K′, will be drawn *forwards.* It therefore follows that the two knees, K and K′, are pressed *alternately backwards* and *forwards.* The foot, F′, when the knee, K′, is drawn forward, is lifted by the means already described for the foot, F.

It will be apparent, from this description, that the piece of mechanism here exhibited is a contrivance derived from the motion of the legs of an animal, and resembling in all respects the fore legs of a horse. It is, however, to be regarded rather as a specimen of great ingenuity than as a contrivance of practical utility.

(86.) It was about this period that the important fact was first ascertained that the adhesion or friction of the wheels with the rails on which they moved was amply sufficient to propel the carriage, even when dragging after it a load of great weight; and that, in such case, the progressive motion would be effected without any slipping of the wheels. The consequence of this fact rendered totally useless all the contrivances for giving wheels a purchase on the road, such as racks, chains, feet, &c. The experiment by which this was determined appears to have been first tried on the Wylam railroad; where it was proved, that, when the road was level, and the rails clean, the adhesion of the wheels was sufficient, in all kinds of weather, to propel considerable loads. By manual labour it was first ascertained how much weight the wheels of a common carriage would overcome without slipping round on the rail; and having found the proportion which that bore to the weight, they then ascertained that the weight of the engine would produce sufficient adhesion to drag after it, on the railroad, the requisite number of waggons.*

In 1814, an engine was constructed at Killingworth, by Mr. *Stephenson*, having two cylinders with a cylindrical boiler, and working two pair of wheels, by cranks placed at right angles; so that when the one was in full operation, the other was at its dead points. By these means the propelling power was always in action. The cranks were maintained in this position by an endless chain, which passed round two cogged wheels placed under the engine, and which were fixed on the same axles on which the wheels were placed. The wheels in this case were fixed on the axles, and turned with them.

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* Wood on Railroads, 2d edit. p. 133.

This engine is represented in fig. 54., the sides being open, to render the interior mechanism visible. A B is the cylindrical boiler; C C are the working cylinders; D E are the cogged wheels

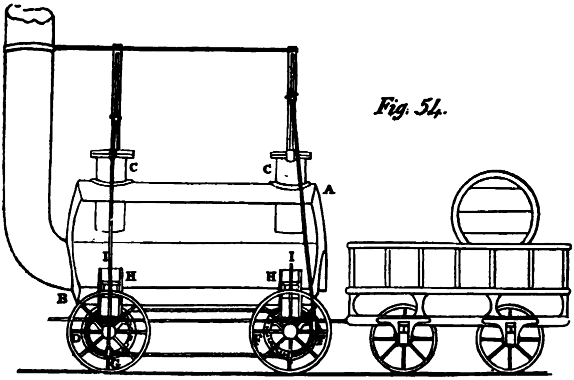


Fig. 54.

fixed on the axle of the wheels of the engine, and surrounded by the endless chain. These wheels being equal in magnitude, perform their revolutions in the same time; so that, when the crank F descends to the lowest point, the crank G rises from the lowest point to the horizontal position D; and, again, when the crank F rises from the lowest point to the horizontal position E, the other crank rises to the highest point; and so on. A very beautiful contrivance was adopted in this engine, by which it was suspended on springs of steam. Small cylinders, represented at H, are screwed by flanges to one side of the boiler, and project within it a few inches; they have free communication at the top with the water or steam of the boiler. Solid pistons are represented at I, which move steam-tight in these cylinders; the cylinders are open at the bottom, and the piston-rods are screwed on the carriage of the engine, over the axle of each pair of wheels, the pistons being presented upwards. As the engine is represented in the figure, it is supported on four pistons, two at each side. The pistons are pressed upon by the water or steam which occupy the upper chamber of the cylinder; and the latter being elastic in a high degree, the engine has all the advantage of spring suspension. The defect of this method of supporting the engine is, that when the steam loses that amount of elasticity necessary for the support of the machine, the pistons are forced into the cylinders, and the bottoms of the cylinders bear upon them. All spring suspension is then lost. This mode of suspension has, consequently, since been laid aside.

In an engine subsequently constructed by Mr. *Stephenson*, for the Killingworth railroad, the mode adopted of connecting the wheels by an endless chain and cog-wheels was abandoned; and the same effect was produced by connecting the two cranks by a straight rod. All such contrivances, however, have this great defect, that, if the fore and hind wheels be not constructed with dimensions accurately equal, there must necessarily be a slipping or dragging on the road. The nature of the machinery requires that each wheel should perform its revolution exactly in the same time; and, consequently, in doing so, must pass over exactly equal lengths of the road. If, therefore, the circumference of the wheels be not accurately equal, that wheel which has the lesser circumference must be dragged along so much of the road as that by which it falls short of the circumference of the greater wheel; or, on the other hand, the greater wheel must be dragged in the opposite direction, to compensate for the same difference. As no mechanism can accomplish a perfect equality in four, much less in six, wheels, it may be assumed that a great portion of that dragging effect is a necessary consequence of the principle of this machine; and even were the wheels, in the first instance, accurately constructed, it is not possible that their wear could be so exactly uniform as to continue equal.

(87.) The next stimulus which the progress of this invention received, proceeded from the great national work undertaken at Liverpool, by which that town and the extensive commercial mart of Manchester were connected by a double line of railway. When this project was undertaken, it was not decided what moving power it might be most expedient to adopt as a means of transport on the proposed road: the choice lay between horse power, fixed steam-engines, and locomotive engines; but the first, for many obvious reasons, was at once rejected in favour of one or other of the last two.

The steam-engine may be applied, by two distinct methods, to move waggons either on a turnpike road or on a railway. By the one method the steam-engine is fixed, and draws the carriage or train of carriages towards it by a chain extending the whole length of road on which the engine works. By this method the line of road over which the transport is conducted is divided into a number of short intervals, at the extremity of each of which an engine is placed. The waggons or carriages, when drawn by any engine to its own station, are detached, and connected with the extremity of the chain worked by the next stationary engine; and thus the journey is performed, from station to station, by separate engines. By the other method the same engine draws the load the whole journey, travelling with it.

The Directors of the Liverpool and Manchester railroad, when that work was advanced towards its completion, employed, in the spring of the year 1829, Messrs. *Stephenson* and *Lock*, and Messrs. *Walker* and *Rastrick*, experienced engineers, to visit the different railways where practical information respecting the comparative effects of stationary and locomotive engines was likely to be obtained; and from these gentlemen they received reports on the relative merits, according to their judgment, of the two methods. The particulars of their calculations are given at large in the valuable work of Mr. *Nicholas Wood* on railways; to which we refer the reader, not only on this, but on many other subjects connected with the locomotive steam-engine, into which it would be foreign to our object to enter. The result of the comparison of the two systems was, that the capital necessary to be advanced to establish a line of stationary engines was considerably greater than that which was necessary to establish an equivalent power in locomotive engines; that the annual expense by the stationary engines was likewise greater; and that, consequently, the expense of transport by the latter was greater in a like proportion. The subjoined table exhibits the results numerically: —

	Capital.			Annual Expense.			Expense of taking a Ton of Goods one Mile.
	£	s.	d.	£	s.	d.	
Locomotive Engines -	58,000	0	0	25,517	8	2	0·164 of a penny.
Stationary Engines - -	121,496	7	0	42,031	16	5	0·269
Locomotive System - less	63,496	7	0	16,514	8	3	0·105

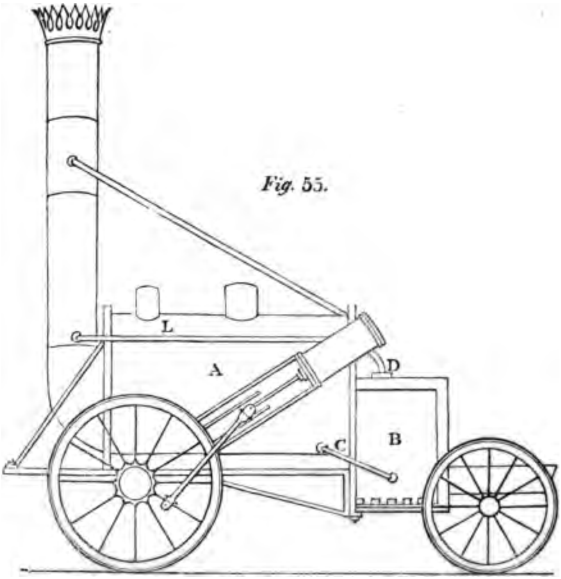
On the score of economy, therefore, the system of locomotive engines was entitled to a decided preference; but there were other considerations which conspired with this to decide the choice of the Directors in its favour. An accident occurring in any part of a road worked by stationary engines must necessarily produce a total suspension of work along the entire line. The most vigilant and active attention on the part of every workman, however employed, in every part of the line, would, therefore, be necessary; but, independently of this, accidents arising from the fracture or derangement of any of the chains, or from the suspension of the working of any of the fixed engines, would be equally injurious, and would effectually stop the intercourse along the line. On the other hand, in locomotive engines an accident could only affect the particular train of carriages drawn by the engine to which the accident might occur; and even then the difficulty could be remedied by having a supply of spare engines at convenient stations along the line. It is true that the *probability* of accident is, perhaps, less in the stationary than in the locomotive system; but the *injurious consequences*, when accident *does* happen, are prodigiously greater in the former. "The one system," says Mr. *Walker*, "is like a chain extending from Liverpool to Manchester, the failure of a single link of which would destroy the whole; while the other is like a number of short and unconnected chains," the destruction of any one of which does not interfere with the effect of the others, and the loss of which may be supplied with facility.

The decision of the Directors was, therefore, in favour of locomotive engines; and their next measure was to devise some means by which the inventive genius of the country might be stimulated to supply them with the best possible form of engines for this purpose. With this view, it was proposed and carried into effect to offer a prize for the best locomotive engine which might be produced under certain proposed conditions, and to appoint a time for a public trial of the claims of the candidates. A premium of 500*l.* was accordingly offered for the most improved locomotive engine to run on the Liverpool and Manchester Railway; under the conditions that they should produce no smoke; that the pressure of the steam should be limited to 50 lbs. on the inch; and that they should draw at least three times their own weight, at the rate of not less than ten miles an hour; that the engine should be supported on springs, and should not exceed fifteen feet in height. Precautions were also proposed against the consequences of the boiler bursting; and other matters, not necessary to mention more particularly here. This proposal was announced in the spring of 1829, and the time of trial was appointed in the following October. The engines which underwent the trial were, the Rocket, constructed by Mr. *Stephenson*; the Sanspareil, by *Hackworth*; and the Novelty, by Messrs. *Braithwait* and *Ericson*. Of these, the Rocket obtained the premium. A line of railway was selected for the trial, on a level piece of road about two miles in length, near a place called Rainhill, between Liverpool and Manchester; the distance between the two stations was a mile and a half, and the engine had to travel this distance backwards and forwards ten times, which made altogether a journey of 30 miles. The Rocket performed this journey twice: the first time, in 2 hours 14 minutes and 8 seconds; and the second time, in 2 hours 6 minutes and 49 seconds. Its speed at different parts of the journey varied: its greatest rate of motion was rather above 29 miles an hour; and its least, about 11½ miles an hour. The average rate of the one journey was $13\frac{4}{10}$ miles an hour; and of the other, $14\frac{2}{10}$ miles. This was the only engine which performed the complete journey proposed, the others having been stopped from accidents which occurred to them in the experiment. The Sanspareil performed the distance between the stations eight times, travelling 22½ miles in 1 hour 37 minutes and 16 seconds. The greatest velocity to which this engine attained was something less than 23 miles per hour. The Novelty had only passed twice between the stations when the joints of the boiler gave way, and put an end to the experiment.

(88.) The great object to be attained in the construction of these engines was, to combine with sufficient lightness the greatest possible heating power, The fire necessarily acts on the water in two ways: first, by its radiant heat; and, second, by the current of heated air which is carried by the draft through the fire, and finally passes into the chimney. To accomplish this object, therefore, it is necessary to expose to both these sources of heat the greatest possible quantity of surface in contact with the water. These ends were attained by the following admirable arrangement in the Rocket: —

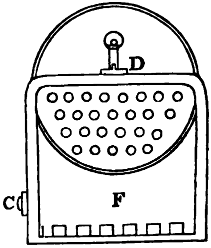
This engine is represented in fig. 55. It is supported on four wheels; the principal part of the weight being thrown on one pair which are worked by the engine. The boiler consists of a cylinder 6 feet in length, with flat ends; the chimney issues from one end, and to the other end is attached a square box, B, the bottom

Fig. 55.



of which is furnished with the grate on which the fuel is placed. This box is composed of two casings of iron, one contained within the other, having between them a space about 3 inches in breadth; the magnitude of the box being 3 feet in length, 2 feet in width, and 3 feet in depth. The casing which surrounds the box communicates with the lower part of the boiler by a pipe marked C; and the same casing at the top of the box communicates with the upper part of the boiler by another pipe marked D. When water is admitted into the boiler, therefore, it flows freely, through the pipe C, into the casing which surrounds the furnace or fire-box, and fills this casing to the same level as that which it has in the boiler. When the engine is at work, the boiler is kept about half filled with water; and, consequently, the casing surrounding the furnace is completely filled. The steam which is generated in the water contained in the casing finds its exit through the pipe D, and escapes into the upper part of the boiler. A section of the engine, taken at right angles to its length, is represented at fig. 56. Through the lower part of the boiler pass a number of copper tubes of small size, which communicate at one end with the fire-box, and at the other with the chimney, and form a passage for the heated air from the furnace to the chimney. The ignited fuel spread on the grate at the bottom of the fire-box disperses its heat by radiation, and acts in this manner on the whole surface of the casing surrounding the fire-box; and thus raises the temperature of the thin shell of water contained in that casing. The chief part of the water in the casing being lower in its position than the water in the boiler, acquires a tendency to ascend when heated, and passes into the boiler; so that a constant circulation of the heated water is maintained, and the water in the boiler must necessarily be kept at nearly the same temperature as the water in the casing. The air which passes through the burning fuel, and which fills the fire-box, is carried by the draft through the tubes which extend through the lower part of the boiler; and as these tubes are surrounded on every side with the water contained in the boiler, this air transmits its heat through these tubes to the water. It finally issues into the chimney, and rises by the draft. The power of this furnace must necessarily depend on the power of draft in the chimney; and to increase this, and at the same time to dispose

Fig. 56.



of the waste steam after it has worked the piston, this steam is carried off by a pipe, L, which passes from the cylinder to the chimney, and escapes there in a jet which is turned upwards. By the velocity with which it issues from this jet, and by its great comparative levity, it produces a strong current upwards in the chimney, and thus gives force to the draft of the furnace. In fig. 56. the grate-bars are represented at the bottom of the fire-box at F. There are two cylinders, one of which works each wheel; one only appearing in the drawing, fig. 55., the other being concealed by the engine. The spokes which these cylinders work are placed at right angles on the wheels; the wheels being fixed on a common axle, with which they turn.

In this engine, the surface of water surrounding the fire-box, exposed to the action of radiant heat, amounted to 20 square feet, which received heat from the surface of 6 square feet of burning fuel on the bars. The surface exposed to the action of the heated air amounted to 118 square feet. The engine drew after it another carriage, containing fuel and water; the fuel used was coke, for the purpose of avoiding the production of smoke.

(89.) The Sanspareil of Mr. *Hackworth* is represented in fig. 57.; the horizontal section being exhibited in fig. 58.

The draft of the furnace is produced in the same manner as in the Rocket, by ejecting the waste steam coming from the cylinder into the chimney; the boiler, however, differs considerably from that of the Rocket. A recurved tube passes through the boiler, somewhat similar to that already described in the early engine of Messrs. *Trevethick* and *Vivian*. In the horizontal section (fig. 58.), D expresses the opening of the furnace at the end of the boiler, beside the chimney. The grate-bars appear at A, supporting the burning fuel; and a curved tube passing through the boiler, and terminating in the chimney, is expressed at B, the direction of the draft being indicated by the arrow; C is a section of the chimney. The cylinders are placed, as in the Rocket, on

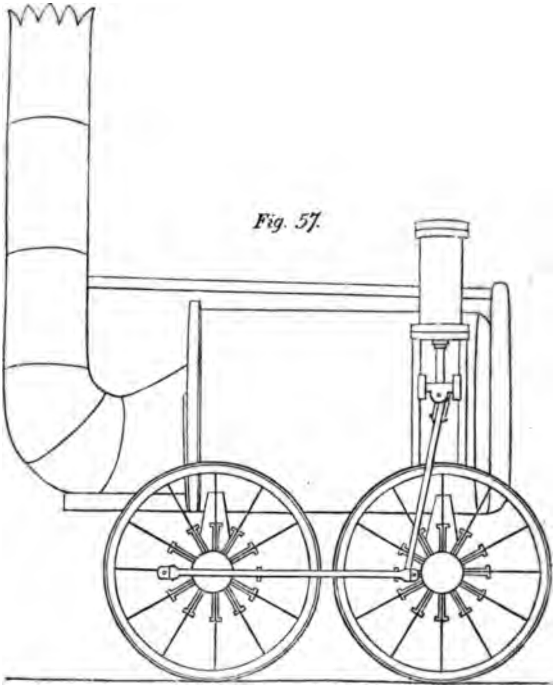
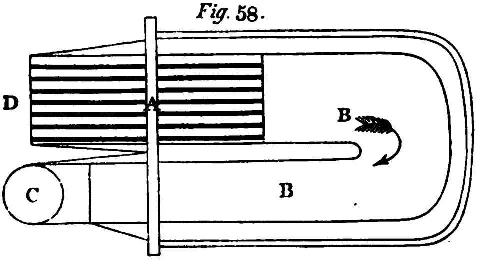


Fig. 57.

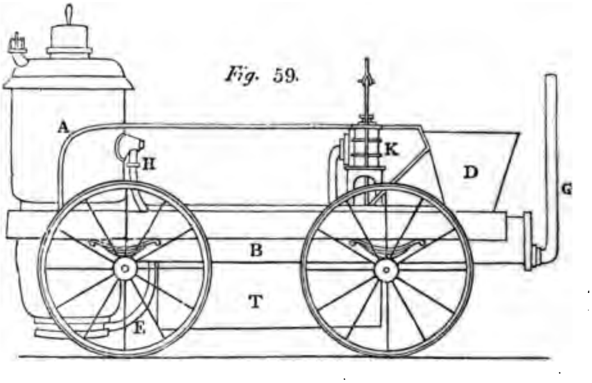
Fig. 58.



each side of the boiler; each working a separate wheel, but acting on spokes placed at right angles to each other. The tube in which the grate and flue are placed diminishes in diameter as it approaches the chimney. At the mouth where the grate was placed its diameter was 2 feet, and it was gradually reduced, so that, at the chimney its diameter was only 15 inches. The grate-bars extended 5 feet into the tube. The surface of water exposed to the radiant heat of the fire was 16 square feet; and that exposed to the action of the heated air and flame was about 75 square feet. The magnitude of the grate, or sheet of burning fuel which radiated heat, was 10 square feet.

(90.) The Novelty, of Messrs. *Braithwaite* and *Ericson*, is represented in fig. 59.; and a section of the generator and boiler is exhibited in fig. 60.; the corresponding parts in the two figures are marked by the same letters.

Fig. 59.



A is the generator or receiver, containing the steam which works the engine; this communicates with a lower generator, B, which extends in a horizontal direction the entire length of the carriage. Within the generator A is contained the furnace F, which communicates in a tube C; carried up through the generator, and terminated at the top by sliding shutters, which exclude the air, and which are only opened to supply fuel to the grate F. Below the grate the furnace is not open, as usual, to the atmosphere, but communicates by a tube, E, with a bellows, D; which is worked by the engine, and which forces a constant stream of air, by the tube E, through the fuel on F, so as to keep that fuel in vivid combustion. The heated air contained in the furnace F is driven on, by the same force, through a small curved tube marked *e*, which circulates like a worm (as represented in fig. 60.) through the horizontal generator or receiver; and tapering gradually, until reduced to very small dimensions, it finally issues into the chimney G. The air, in passing along this tube, imparts its heat to the water by which the tube is surrounded, and is brought to a considerably reduced temperature when discharged into the chimney. The cylinder which is represented at K works one pair of wheels, by means of a bell-crank; the other pair, when necessary, being connected with them.

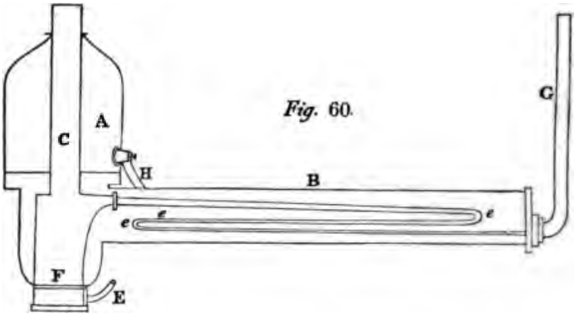


Fig. 60.

In this engine, the magnitude of the surface of burning fuel on the grate-bars is less than 2 square feet; the surface exposed to radiant heat is 9½ square feet; and the surface of water exposed to heated air is about 33 square feet.

The superiority of the Rocket may be attributed chiefly to the greater quantity of surface of the water which is exposed to the action of the fire. With a less extent of grate-bars than the Sanspareil, in the proportion of 3 to 5, it exposes a greater surface of water to radiant heat, in the proportion of 4 to 3; and a greater surface of water to heated air, in the proportion of more than 3 to 2. It was found that the Rocket, compared with the Sanspareil, consumed fuel, in the evaporation of a given quantity of water, in the proportion of 11 to 28. The suggestion of using the tubes to conduct through the water the heated air to the chimney is due to Mr. *Booth*, treasurer of the Liverpool and Manchester Railway Company; and, certainly, nothing has been more conducive to the efficiency of the engines since used than this improvement. It is much to be regretted that the ingenious gentleman who suggested this has reaped none of the advantages to which a patentee would be legally entitled.*

(91.) The great object to be effected in the boilers of these engines is, to keep a small quantity of water at an excessive temperature, by means of a small quantity of fuel kept in the most active state of combustion. To accomplish this, it is necessary, first, so to shape the boiler, furnace, and flues, that the water shall be in contact with as extensive a surface as possible, every part of which is acted on either immediately, by the heat radiating from the fire, or mediately, by the air which has passed through the fire, and which finally rushes into the chimney: and, secondly, that such a forcible draft should be maintained in the furnace that a quantity of heat shall be extricated from the fuel by combustion sufficient to maintain the water at the necessary temperature, and to produce the steam with sufficient rapidity. To accomplish these objects, therefore, the chamber containing the grate should be completely surrounded by water, and should be below the level of the water in the boiler. The magnitude of the surface exposed to radiation should be as great as is consistent with the whole magnitude of the machine. The comparative advantage which the Rocket possessed in these respects over the other engines will be evident on inspection. In the next place, it is necessary that the heat, which is absorbed by the air passing through the fuel, and keeping it in a state of combustion, should be transferred to the water before the air escapes into the chimney. Air being a bad conductor of heat, to accomplish this it is necessary that the air in the flues should be exposed to as great an extent of surface in contact with the water as possible. No contrivance can be less adapted for the attainment of this end than one or two large tubes traversing the boiler, as in the earliest locomotive engines; the body of air which passed through the centre of these tubes had no contact with their surface, and, consequently, passed into the chimney at nearly the same temperature as that which it had when it quitted the fire. The only portion of air which imparted its heat to the water was that portion which passed next to the surface of the tube.

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* Mr. *Booth* received a part of the premium of 500*l.*, but has not participated in any degree in the profits of the manufacture of the engines. In the actual state of the patent laws he thought it not advisable to take a patent.

Several methods suggest themselves to increase the surface of water in contact with a given quantity of air passing through it. This would be accomplished by causing the air to pass between plates placed near each other, so as to divide the current into thin strata, having between them strata of water; or it might be made to pass between tubes differing slightly in diameter, the water passing through an inner tube, and being also in contact with the external surface of the outer tube. Such a method would be similar in principle to the steam-jacket used in *Watt's* steam-engines, or to the condenser of *Cartwright's* engine, already described. But considering the facility of constructing small tubes, and of placing them in the boiler, that method perhaps is, on the whole, the best in practice; although the shape of a tube, geometrically considered, is most unfavourable for the exposure of a fluid contained in it to its surface. The air which passes from the fire-chamber, being subdivided as it passes through the boiler by a great number of very small tubes, may be made to impart all its excess of heat to the water before it issues into the chimney. This is all which the most refined contrivance can effect. The Rocket engine was traversed by 25 tubes, each 3 inches in diameter; and the principle has since been carried to a much greater extent.

The total abstraction of heat from the air before it reaches the chimney is attended with one consequence, which, at first view, would present a difficulty apparently insurmountable; the chimney would, in fact, lose all power of draft. This difficulty, however, was removed by using the waste steam which had passed from the cylinder after working the engine for the purpose of producing a draft. This steam, as in Mr. *Stephenson's* earlier engines, was urged through a jet presented upwards in the chimney, and driven out with such force in that direction as to create a sufficient draft to work the furnace.

It will be observed that the principle of draft in the Novelty is totally distinct from this: in that engine the draft is produced by a bellows worked by the engine. The question, as far as relates to these two methods, is, whether more power is lost in supplying the steam through the jet, as in the Rocket, or in working the bellows, as in the Novelty. The force requisite to impel the steam through the jet must be exerted by the returning stroke of the piston, and, consequently, must rob the working effect to an equivalent amount. On the other hand, the power requisite to work the bellows in the Novelty must be subducted from the available power of the engine. I apprehend that the former method is more effectual and economical.

The importance of these details will be understood, when it is considered that the only limit to the attainment of speed by locomotive engines is the power to produce in a given time a certain quantity of steam. Each stroke of the cylinder causes one revolution of the wheels, and consumes two cylinders full of steam: consequently, a cylinder of steam corresponds to a certain number of feet of road travelled over: hence it is that the production of a rapid and abundant supply of heat, and the imparting of that heat quickly and effectually to the water, is the key to the solution of the problem to construct an engine capable of rapid motion.

The method of subdividing the flue into tubes was carried much further by Mr. *Stephenson* after the construction of the Rocket; and, indeed, the principle was so very obvious, that it is only surprising that, in the first instance, tubes of smaller diameter than 3 inches were not used. In engines since constructed, the number of tubes vary from 90 to 100, the diameter being reduced to 2 inches or less, and in some instances tubes have been introduced even to the number of 150, of 1½ inch diameter. In the Meteor, 20 square feet are exposed to radiation, and 139 to the contact of heated air; in the Arrow, 20 square feet to radiation, and 145 to the contact of heated air. The superior economy of fuel gained by this means will be apparent by inspecting the following table, which exhibits the consumption of fuel requisite to convey a ton weight a mile in each of four engines, expressing also the rate of the motion:—

Engines.	Average rate of speed in miles per hour.	Consumption of Coke in pounds per ton per mile.
No. 1. Rocket -	14	2·41
2. Sanspareil -	15	2·47
3. Phœnix -	12	1·42
4. Arrow -	12	1·25

(92.) Since the period at which the railway was opened for the actual purposes of transport, the locomotive engines have been in a state of progressive improvement. Scarcely a month has passed without suggesting some change in the details, by which fuel might be economised, the production of steam rendered more rapid, the wear of the engine rendered slower, the proportionate strength of the different parts improved, or some other desirable end obtained. The consequence of this has been, that the particular engines to which we have alluded, and others of the same class, without having, as it were, lived their natural life, or without having been worn out by work, have been laid aside to give place to others of improved powers. By the exposure of the cylinders to the atmosphere in the Rocket, and engines of a similar form, a great waste of heat was incurred, and it was accordingly determined to remove them from the exterior of the boiler, and to place them within a casing immediately under the chimney: this chamber was necessarily kept warm by its proximity to the end of the boiler, but more by the current of heated air, which constantly rushed into it from the tubes. This change, also, rendered necessary another, which improved the working of the engine. In the earlier engines the motion of the piston was communicated to the wheel by a connecting rod attached to one of the spokes on the exterior of the wheel, as represented in fig. 55. By the change to which we have just alluded, the cylinders being placed between the wheels under the chimney, this mode of working became inapplicable, and it was considered better to connect the piston-rods with two cranks placed at right angles on the axles of the great wheels. By this means it was found, that the working of the machine was more even, and productive of less strain than in the former arrangement. On the other hand, a serious disadvantage was incurred by the adoption of a cranked axle. The weakness necessarily arising from such a form of axle could only be counterbalanced by great thickness and weight of metal; and even this precaution does not prevent the occasional fracture of such axles at the angles of the cranks. The advantages, however, of this plan, on the whole, are considered to predominate.

In the most improved engines in present use two safety valves are provided, of which one only is in the power of the engine man. The tubes being smaller and more numerous than in the earlier engines, the heat is more completely extracted from the air before it enters the chimney. A powerful draft is rendered still more necessary by the smallness of the tubes: this is effected by forcing the steam which has worked the pistons through a contracted orifice, presented upwards in the chimney, by the regulation of which any degree of draft may be obtained.

One of the most improved engines at present in use is represented in fig. 61.

A represents the cylindrical boiler, the lower half of which is traversed by tubes, as described in the Rocket. They are usually from 80 to 100 in number, and about 1½ inch in diameter; the boiler is about 7 feet in length; the fire-chamber is attached to one end of it at F, as in the Rocket, and similar in construction; the cylinders are inserted in a chamber at the other end, immediately under the chimney. The piston-rods are supported in the horizontal position by guides; and connecting rods extend from them, under the engine, to the two cranks placed on the axle of the large wheels. The effects of any inequality in the road are counteracted by springs, on which the engine rests, the springs being below the axle of the great wheels, and above that of the less. The steam is supplied to the cylinders, and withdrawn, by means of the common sliding valves, which are worked by an eccentric wheel placed on the axle of the large wheels of the carriage. The motion is communicated from this eccentric wheel to the valve by sliding rods. The stand is placed for the

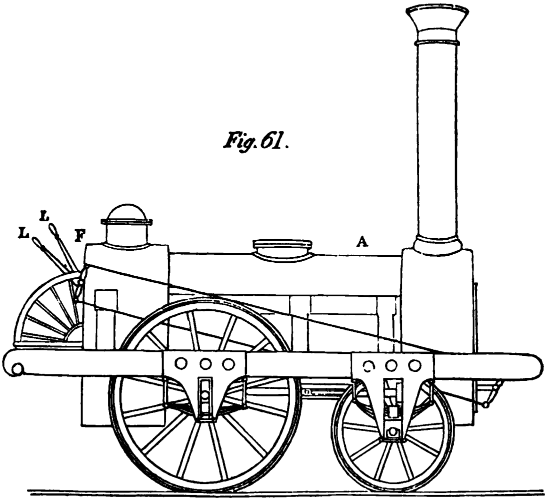

Fig. 61.

attendant at the end of the engine, next the fire-place F; and two levers L project from the end, which communicate with the valves by means of rods, by which the engine is governed, so as to stop or reverse the motion.

The wheels of these engines have been commonly constructed of wood, with strong iron tires, furnished with flanges adapted to the rails. But Mr. *Stephenson* has recently substituted in some instances wheels of iron with hollow spokes. The engine draws after it a tender carriage containing the fuel and water, and when carrying a light load is capable of performing the whole journey from Liverpool to Manchester without a fresh supply of water. When a heavy load of merchandise is drawn, it is usual to take in water at the middle of the trip.

(93.) In reviewing all that has been stated, it will be perceived that the efficiency of the locomotive engines used on this railway is mainly owing to three circumstances: 1st, The unlimited power of draft in the furnace, by projecting the waste steam into the chimney; 2d, The unlimited abstraction of heat from the air passing from the furnace, by Mr. *Booth*'s ingenious arrangement of tubes traversing the boiler; and, 3d, Keeping the cylinders warm, by immersing them in the chamber under the chimney. There are many minor details which might be noticed with approbation, but these constitute the main features of the improvements, and should never, for a moment, be lost sight of by projectors of locomotive engines.

The successive introduction of improvements in the engines, some of which we have mentioned, has been accompanied by corresponding accessions to their practical power, and to the economy of fuel; and they have now arrived at a point which is as far beyond the former expectations of the most sanguine locomotive projectors, as it assuredly is short of the perfection of which these wonderful machines are still susceptible.

On a late occasion I had several opportunities, through the favour of the directors of the railway, of witnessing the performance, and ascertaining the capabilities, of the best engines at present used. It will, perhaps, be sufficient to give here the particulars of three experiments; the results of which, I believe, exceeded those of any former trial, and for the accuracy of which I can vouch.

I.

On Saturday, the 5th of May, the engine called the "Victory" took 20 waggons of merchandise, weighing gross 92 tons 19 cwt. 1 qr., together with the tender containing fuel and water, of the weight of which I have no account, from Liverpool to Manchester (30 miles) in 1 h. 34 min. 45 sec. The train stopped to take in water half-way, for 10 minutes, not included in the above-mentioned time. On the inclined plane rising 1 in 96, and extending 1½ mile, the engine was assisted by another engine called the "Samson," and the ascent was performed in 9 minutes. At starting the fire-place was well filled with coke, and the coke supplied to the tender accurately weighed. On arriving at Manchester the fire-place was again filled, and the coke remaining in the tender weighed. The consumption was found to amount to 929 pounds net weight, being at the rate of one third of a pound per ton per mile.

Speed on the level was 18 miles an hour; on a fall of 4 feet in a mile, 21½ miles an hour; fall of 6 feet in a mile, 25½ miles an hour; on the rise over Chatmoss, 8 feet in a mile, 17⅝ miles an hour; on level ground sheltered from the wind 20 miles an hour. The wind was moderate, but direct ahead. The working wheels slipped three times on Chatmoss, and the train was retarded from 2 to 3 minutes.

The engine, on this occasion, was not examined before or after the journey, but was presumed to be in good working order.

II.

On Tuesday, the 8th of May, the same engine performed the same journey, with 20 waggons, weighing gross 90 tons 7 cwt. 2 qrs., exclusive of the unascertained weight of the tender. The time of the journey was 1 h. 41 min. The consumption of coke 1040 lbs. net weight, estimated as before. Rate of speed: —

Level - -	17⅝ miles per hour.
Fall of 4 feet in a mile	22
——— 6 - -	22½
Rise of 8 feet in a mile	15

On this occasion there was a high wind ahead on the quarter, and the connecting rod worked hot, owing to having been keyed too tight. On arriving at Manchester, I caused the cylinders to be opened, and found that the pistons were so loose, that the steam blew through the cylinders with great violence. By this cause, therefore, the machine was robbed of a part of its power during the journey; and this circumstance may explain the slight decrease in speed, and increase in the consumption of fuel, with a lighter load in this journey compared with that performed on the 5th of May.

The Victory weighs 8 tons 2 cwt., of which 5 tons 4 cwt. rest on the drawing wheels. The cylinders are 11 inches diameter, and 16 inches stroke, and the diameter of the drawing wheels is 5 feet.

III.

On the 29th of May, the engine called the "Samson" (weighing 10 tons 2 cwt., with 14-inch cylinders, and 16-inch stroke; wheels 4 feet 6 inches diameter, both pairs being worked by the engine; steam 50 lbs. pressure, 130 tubes,) was attached to 50 waggons laden with merchandise, net weight about 150 tons gross weight, including waggons, tender, &c., 223 tons 6 cwt. The engine with this load travelled from Liverpool to Manchester (30 miles) in 2 h. and 40 min., exclusive of delays upon the road for watering, &c., being at the rate of nearly 12 miles an hour. The speed varied according to the inclinations of the road. Upon a level it was 12 miles an hour; upon a descent of 6 feet in a mile it was 16 miles an hour; upon a rise of 8 feet in a mile, it was about 9 miles an hour. The weather was calm, the rails very wet; but the wheels did not slip even in the slowest speed, except at starting, the rails being at that place soiled and greasy, with the slime and dirt to which they are always exposed at the stations. The coke consumed in this journey, exclusive of what was raised in getting up the steam, was 1762 lbs., being at the rate of a quarter of a pound per ton per mile.

(94.) From the above experiments it appears, that a locomotive engine, in good working order, with its full complement of load, is capable of transporting weights at an expense in fuel amounting to about 4 ounces of coke per ton per mile. The attendance required on the journey is that of an engine-man and a fire-boy; the former being paid 1*s.* 6*d.* for each trip of 30 miles, and the latter 1*s.* In practice, however, we are to consider, that it rarely happens that the full complement of load can be sent with the engines; and when lesser loads are transported, the *proportionate expense* must, for obvious reasons, be greater. During the last winter, the loads commonly transported by engines like the Victory were about 35 tons; latterly they have been considerably increased; and at present, with the assistance of another engine on the inclined plane, the ordinary load is, I am informed, about 100 tons gross.

(95.) Having explained the power and efficiency of these locomotive engines, it is now right to notice some of the defects under which they labour.

The great original cost, and the heavy expense of keeping the engines used on the railway in repair, have pressed severely on the resources of the undertaking. One of the best constructed of the later engines costs originally about 800*l.* With all possible allowances for the difficulties to be encountered by engineers in the construction of machines of a novel description, this price appears to be excessive. It may be hoped that by the excitement of competition, the facilities derived from practice, and from the manufacture of a greater number of engines of the same kind, considerable reduction of this cost may be effected. The original cost, however, is far from being the principal source of expense; the wear and tear of these machines, and the occasional fracture of those parts on which the greatest strain has been laid, have greatly exceeded what the directors had anticipated. Although this source of expense must be in part attributed to the engines not having yet attained that state of perfection in the proportion and adjustment of their parts, of which they are susceptible, and to which experience alone can lead, yet there are some obvious defects which demand immediate attention.

The heads of the cylindrical boilers are flat, and formed of iron, similar to the material of the boilers themselves. The tubes which traverse the boiler are copper, and are inserted in the flat circular ends so as to be water-tight; when the boiler is heated, it is found that the tubes expand in a greater degree than the other parts of the boiler. The consequence of this is, either that the tubes soon become loosened at the extremities, so as to cause the boiler to leak, or, from not having room to expand, they bend. This causes a continual necessity for removing and refastening the tubes.

It will be recollected that the fire-place is situated at one end of the boiler, immediately below the mouths of the tubes; a powerful draft of air, passing through the fire, carries with it ashes and cinders, which are driven violently through the tubes, and especially the lower ones, situated near the fuel. These tubes are, by this means, subject to rapid wear, the cinders continually acting upon their interior surface. After a short time it becomes necessary to replace single tubes, according as they are found to be worn, by new ones; and it not unfrequently happens, when this is neglected, that tubes burst. After a certain length of time the engines require new tubing, which is done at the expense of about 70*l.*, allowing for the value of the old tubes. This rapid wear of the tubes might possibly be avoided by constructing the fire-place in a lower position, so as to be more removed from their mouths; or still more effectually by interposing a casing of metal, which might be filled with water, between the fire-place and those tubes which are the most exposed to the cinders and ashes. The unequal expansion of the tubes and boilers appears to be an incurable defect, if the present form of the engine be retained. If the fire-place and chimney could be placed at the same end of the boiler, so that the tubes might be recurved, the unequal expansion would then produce no injurious effect; but it would be difficult to clean the tubes, if they were exposed, as they are at present, to the cinders. The next source of expense arises from the wear of the boiler-heads, which is exposed to the action of the fire. These have already required frequent patching; and in many of the engines now used they will be speedily required to be renewed.

It has been said by some whose opinions are adverse to the advantages of railways, but more especially to the particular species of locomotive engines now under consideration, that the repairs of one of these engines cost so great a sum as 1500*l.* per annum, and that the directors now think of abandoning them, or adopting either stationary engines or horse power. As to the first of these statements I must observe, that the expense of repairs of such machines should never be computed in reference to *time*, but rather in reference to the work done, or the distance travelled over. I have lately ascertained that the engines travel a distance of from 25,000 to 30,000 miles before they require new tubing. During that work, however, single tubes are of course occasionally renewed, and other repairs are made, the expense of which may safely be stated as under the original cost of the engine. The second statement, that the company contemplate substituting stationary engines, or horses for locomotives, is altogether at variance with the truth. Whatever improvements may be contemplated in locomotives, the directors assuredly have not the slightest intention of going back in the progress of improvement, in the manner just mentioned.

(96.) The advantages derivable from rail-roads are greatly abridged by the difficulty arising from those changes of level to which all roads are necessarily liable; but in the case of rail-roads, from causes peculiar to themselves, these changes of level occasion great inconvenience. To explain the nature of these difficulties, it will be necessary to consider the relative proportion which must subsist between the power of traction on a level and on an inclined plain. On a level rail-road the force of traction necessary to propel any load placed on wheel carriages may be estimated at about a 240th part of the load; that is to say, if a load of 240 tons were placed upon wheel carriages on a level rail-road, the traces of horses drawing it would be stretched with a force equal to one ton. The necessity of this force of traction, arising from the want of perfect smoothness in the road, and the friction of the wheels and axles of the carriages, must be the same whether the road be level or inclined, and consequently in ascending an inclined plane the same force of traction will be necessary in addition to that which arises from the tendency of the load to fall down the plane. This latter tendency is always in the proportion of the elevation of the plane to its length; that is to say, a plane which rises 1 foot in 100 will give a weight of 100 tons a tendency to fall down the plane amounting to 1 ton, and would therefore add 1 ton to the force of traction necessary for such a load on a level. In like manner, a rise of 1 foot in 240 would give a load of 240 tons a tendency to descend the plane with a force of 1 ton, and would add to the necessary force of traction 1 ton. Hence it appears, that, taking the force of traction on the level at 1 ton to 240, a rise of 1 foot to 240 will require twice as powerful a force of traction as would be necessary on the level. In like manner a rise of 2 feet in 240, or 1 in 120, would require three times the power of traction necessary on the level; and the rise of 3 feet in 240, or 1 in 80, would require four times the traction necessary on a level, and so on.

It will be apparent, therefore, that if a rail-road undulates by inclined planes, even of the most moderate inclinations, the propelling power to be used upon it must be of such a nature as to be capable of increasing its intensity in a great degree, according to the elevation of the planes which it has to encounter. A plane of 1 in 80, presents to the eye scarcely the appearance of an ascent, and yet it rerequires the power of traction to be increased in a four-fold proportion.

It is the property of animal power, that within certain limits its energy can be put forth at will, according to the exigency of the occasion; but the intensity of mechanical power, in the instance now considered, cannot so conveniently be varied, except, indeed, within very narrow limits.

In the application of locomotive engines upon railways the difficulty arising from inclined planes has been attempted to be surmounted by several methods, which we shall now explain.

1. Upon arriving at the foot of the plane the load is divided, and the engine carries it up in several successive trips, descending the plane unloaded after each trip. The objection to this method is the delay which it occasions,—an objection which has great force in the transport of passengers. From what has been stated, it would be necessary, when the engine is fully loaded on a level, to divide its load into four parts, to be successively carried up when the incline rises 1 foot in 80. Upon the Liverpool and Manchester line, an engine fully loaded on the level would require to have its load divided into at least three parts, to be taken up in three trips, on an ascent of 1 foot in 96. This method has been practised in the transport of merchandise occasionally, when heavy loads were carried on the Liverpool and Manchester line.

2. A subsidiary or assistant locomotive engine may be kept in constant readiness at the foot of each incline, for the purpose of aiding the different trains, as they arrive, in ascending. The objection to this method is the cost of keeping such an engine with its boiler continually prepared, and its steam up. It would be necessary to keep its fire continually lighted, whether employed or not; otherwise, when the train would arrive at the foot of the incline, it should wait until the subsidiary engine was prepared for work. In cases where trains would start and arrive at stated times, this objection, however, would have

less force. This method is at present adopted occasionally on the Liverpool and Manchester line.

3. A fixed steam engine may be erected on the crest of the incline, so as to communicate by ropes with the train at the foot. Such an engine would be capable of drawing up one or two trains together, with their locomotives, according as they would arrive, and no delay need be occasioned. This method requires that the fixed engine should be kept constantly prepared for work, and the steam continually up in the boiler.

4. In working on the level, the communication between the boiler and the cylinder in the locomotives may be so restrained by partially closing the throttle valve, as to cause the pressure upon the piston to be less in a considerable degree than the pressure of steam in the boiler. If under such circumstances a sufficient pressure upon the piston can be obtained to draw the load on the level, the throttle valve may be opened on approaching the inclined plane, so as to throw on the piston a pressure increased in the same proportion as the previous pressure in the boiler was greater than that upon the piston. If the fire be sufficiently active to keep up the supply of steam in this manner during the ascent, and if the rise be not greater in proportion than the power thus obtained, the locomotive will draw the load up the incline without further assistance. It is, however, to be observed, that in this case the load upon the engine must be less than the amount which the adhesion of its working wheels with the rail-road is capable of drawing, for this adhesion must be adequate to the

traction of the same load up the incline; otherwise whatever increase of power might be obtained by opening the throttle valve, the drawing wheels would revolve without causing the load to advance. This method has been invariably practised upon the Liverpool and Manchester line in the transport of passengers; and, indeed, it is the only method yet discovered, which is consistent with the expedition necessary for that species of traffic. The objections to this method are, the necessity of maintaining a much higher pressure in the boiler than is sufficient for the purposes of the load upon more level parts of the line, and the difficulty of maintaining such a draft in the furnace during the ascent as to produce a sufficient supply of steam for the engine.

5. The mechanical connection between the piston of the cylinder and the points of contact of the working wheels with the road may be so altered, upon arriving at the incline, as to give the piston a greater power over the working wheels. This may be done in an infinite variety of ways, but hitherto no method has been suggested sufficiently simple to be applicable in practice; and even were any means suggested which would accomplish this, unless the intensity of the impelling power were at the same time increased, it would necessarily follow that the speed of the motion would be diminished in exactly the same proportion as the power of the piston over the working wheels would be increased. Thus, on the inclined plane, which rises 1 in 96, upon the Liverpool line, the speed would be diminished to less than one third of its amount upon the level.

Whatever be the method adopted to surmount inclined planes upon a railway, inconvenience attends the descent upon them. The motion down the incline by the force of gravity is accelerated; and if the train be not retarded, a descent of any considerable length, even at a small elevation, would produce a velocity which would be attended with great danger. The shoe used to retard the descent down hills on turnpike roads cannot be used upon rail-roads, and the application of brakes to the faces of the wheels is likewise attended with great difficulty. The friction produced by the rapid motion of the wheel soon sets fire to wood, and iron would be inadmissible. The action of the steam on the piston may be reversed, so as to act against the motion of the wheels instead of with it; but even this is attended with peculiar difficulty.

From all that has been stated, it will be apparent that, with our present knowledge, considerable inclines are fatal to the profitable performance on a railway, and even small inclinations are attended with great inconvenience.*

(97.) To obtain from the locomotive steam engines now used on the railway the most powerful effects, it is necessary that the load placed on each engine should be very considerable. It is not possible to construct three locomotive engines of this kind, each drawing a load of 30 tons, at the same expense and with the same effect as one locomotive engine drawing 90 tons. Hence arises what must appear an inconvenience and difficulty in applying these engines to one of the most profitable species of transport — the transport of passengers. It is impracticable, even between places of the most considerable intercourse, to obtain loads of passengers sufficiently great at each trip to maintain such an engine working on a railway. A load of 120 passengers will not form more than one sixth of the load which an engine such as the Victory is capable of transporting at the rate of 20 miles an hour.* The difficulty of collecting so considerable a number of persons, at any stated hour, to perform the journey, is obvious; and, therefore, the only method of removing the inconvenience is, *to cause the same engine which transports passengers also to transport goods*, so that the goods may make up the requisite supplement to the load of passengers. In this way, provided the traffic in goods be sufficient, such engines may start with their full complement of load, whatever be the number of passengers.

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* A contrivance might be applied at changes of level in railroads somewhat similar to locks in a canal. The train might be rolled upon a platform which might be raised by machinery, and thus at the change of level there would be as it were *steps* from one level to another, up which the loads would be lifted by any power applied to work the machinery. The advantage in this case would be, that the trains might be adapted to work always upon a level.

Experience seems to have sufficiently proved, that the form of locomotive engine so successfully adopted by Mr. *Stephenson* cannot be adapted with advantage to moderate loads; and it does not appear to me, that any future improvement in this engine is likely to attain this end. When I come to explain the attempts which have been made towards the establishment of steam carriages on turnpike roads, I shall explain the principle and structure of the boiler invented by Mr. *Gurney*, which I consider to be well adapted to work on the railway, and especially so with loads of moderate amount. The directors have lately ordered an engine of this description to be prepared; and I have little doubt that, on trial, it will be found to be better adapted to the conveyance of passengers than the engines now in use.

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* On the occasion of races held at Newton, a place about 15 miles from Liverpool, two engines were sent with trains of carriages to take back to Liverpool the visiters to the races. Some accident prevented one of the engines from working on the occasion, and both trains were attached to the same engine: 800 persons were on this occasion drawn by the single engine to Liverpool, in the space of about an hour.

(98.) The Liverpool and Manchester railway has now been in operation for the conveyance of passengers and merchandise for the space of 18 months, and the practicability of the speculation, considered as a commercial investment, has been fully proved. The extent, however, of its advantages is still unascertained. The expenses attending the work have been greatly increased by the want of previous experience in the construction of fit engines; and although none of the engines constructed can be regarded as failures, yet the course of improvement has been so rapid, that the company have been forced to lay engines aside, not because they performed less than was expected, but because others were contrived which performed more. The expenses of the concern has thus been very materially increased in amount; and any future similar undertaking, profit-ing by the experience thus gained, will effect a corresponding saving.

Notwithstanding these disadvantages, which must inevitably have attended a great public experiment of this nature, the proprietors have already realised a considerable profit on the capital invested, and this profit has been to the present time going on at a rapid rate of increase. The following extract from the half yearly reports of the Company will show the traffic on that road during the year 1831, together with the receipts and expenditure.

1st of January to 1st of July, 1831.

	Tons.
Merchandise between Liverpool and Manchester - -	35,865
Ditto between Liverpool and the Bolton Junction -	6,827
	42,692
Coals from collieries near Liverpool - - -	2,889

Passengers booked at Company's office, 188,726 (exclusive of passengers taken up on the road).

The gross receipts on this traffic were as follows: —

	£	s.	d.
Passengers - - - - - -	43,600	7	5
Merchandise - - - -	21,875	0	1
Coal - - - - - -	218	6	2
	£ 65,693	13	8

Amounting to 4*s.* 7¼*d.* per passenger booked, and 10*s.* 3*d.* per ton for merchandise.

The disbursements upon the same traffic were as follows: —

	£	s.	d.
Coaching department for passengers - -	19,099	16	5
Merchandise, &c. - - - -	16,279	7	5
Total -	35,379	3	10
Profit - - - - -	30,314	9	10
	£65,693	13	8

1st July to 31st December, 1831.

	Tons.
Merchandise between Liverpool and Manchester	52,224
Traffic on the road	2,347
	54,571
Between Liverpool and the Bolton Junction	10,917
Coal from the adjacent collieries	8,396

Passengers booked, exclusive of those taken up on the road, 256,321.

Receipts.

	£	s.	d.
Coach department	58,348	10	0
Merchandise	30,764	17	8
Coal	695	14	4
	£ 89,809	2	0

Expenses.

	£	s.	d.
Passenger department	25,930	1	1
Merchandise	21,841	4	10
Coal department	505	16	3
Bolton Junction	748	16	3
	49,025	18	5
Net profit	40,783	3	7
	£ 89,809	2	0

The capital expended in the completion of the way and works, including engines, coaches, waggons, &c. &c. to 31st December, 1831, amounted to 992,054*l.* 3*s.* 6*d.*

The profits from the opening were as follows: —

	£	s.	d.
From 16th September to 31st December, 1830	14,432	19	5
From 1st January to 30th June, 1831	30,314	9	10
From 1st July to 31st December, 1831	40,783	3	7
Total	£85,530	12	10

The dividends have been as follows: —	£	s.	d.
31st Dec. 1830, 6375 shares of 100*l.* at 2*l.* per share	12,750	0	0
Ditto ditto, to 30th June, 1831, 6375 shares of 100*l.* at 4*l.* 10*s.* per share. Ditto ditto, 6375 shares of 25*l.* at 9*s.* per share - - -	31,556	5	0
Ditto ditto, 31st December, 1831, 7968¾ shares of 100*l.* at 4*l.* 10*s.* per share - - -	35,859	7	6
Total	£80,165	12	6

From the above statement it will appear, that the traffic on the road, as well in passengers as in merchandise, went on continually increasing up to the close of 1831; nor has this increase yet ceased. In the half year ending 31st December, 1831, the average quantity of merchandise conveyed in 6 weeks was 15,112 tons: the quantity conveyed in the 6 weeks ending 23d March, 1832, was 16,632 tons. The receipts in the department for passengers in the 12 weeks ending 23d March, 1831, was 13,965*l.* 6*s.* 11*d.*; and in the 12 weeks ending 23d March, 1832, was 15,496*l.* 11*s.* 3*d.*

In the account of the expenditure contained in the above abstract, considerable sums are included which are in fact unconnected with the railway, and arising altogether from local circumstances. The extremities of the railway being a considerable distance from the centre of business in Liverpool and Manchester, it was found expedient, with a view to encourage the traffic in passengers, that the company should bear the expense of horse carriages to transport the passengers from the centres of the towns to the extremities of the rail-road. This expense, from the 1st of January to 1st of July, 1831, amounted to one third of the sum received for the passengers booked; and from 1st of July to 31st of December, it amounted to nearly half that sum: thus, above 5000*l.* in this item alone should be deducted from the expenditure of the railway transport.* The account of expenses also includes 5647*l.* interest for capital borrowed, which should also be deducted. These would leave the expenditure nearly 11,000*l.* less, and the profits as much more. But besides this, owing to improvements in the engines, the consumption of coke, expenses of repairs, &c. have gone on gradually decreasing. Under all the circumstances now explained there can be no doubt that, while the traffic on the road continues to increase, the expenditure of the Company will be certainly and rapidly diminished, due regard being had to the tonnage and the number of passengers.

Taking the capital invested in the rail-road, engines, carriages, &c., at a million, the profit from January to June 1831 was at the rate of above 6 per cent. per annum; and from the 1st of July to the 31st of December, 1831, it was at the rate of above 8 per cent. per annum; and the confidence of the public in the speculation may be inferred from the fact, that the railway shares of 100*l.* at present sell for above 200*l.*

I cannot conclude my observations on this great national undertaking, without expressing my regret that the directors have not thrown its advantages more open to the population among whom it has sprung up. No visiter can examine the details of the works without being struck with the circumstance that the bulk of the persons engaged upon them [*], in almost every capacity, are strangers to the soil and to the surrounding population, and appear to be brought from another part of the kingdom to reap benefits to which the local population have a moral right, — a right which, I am persuaded, the body of directors and proprietors would, if consulted individually, have respected. It is also to be regretted, that the wise and liberal policy manifested in the celebrated competition, previous to the opening of the railway, has not been so fully followed up in the progress of the undertaking as the public might have hoped from so auspicious a beginning.

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* The Company has lately discontinued the payment of omnibusses for the passengers, and the number of passengers notwithstanding has continued to increase.

In the act of incorporation granted to the Company, they were contemplated principally as a company constructing a road for the accommodation of the public, and were authorised to charge certain tolls for carriages and burdens carried upon that road. They were of course at the same time invested with a certain discretionary power of refusing admission to carriages or engines on the road, if those carriages appeared likely to be injurious to it. The event, however, has presented the Company in another character, viz. in that of carriers upon their own road; and instead of charging a toll to others running upon the road, they are themselves the exclusive monopolists as carriers as well as rail-road proprietors. I am not aware whether instances have occurred of persons applying to engage in the carrying traffic on the line having been refused permission by the directors; but it may be easily imagined that the public will be discouraged from engaging in such competition, when they are conscious that their competitors are also their judges, vested with the power of refusing them at any moment the permission to trade upon the road, under a plea, of the validity of which the directors themselves are the sole judges, their own engineer their sole guide, and from which the public have no appeal. I should regret to be understood as preferring a charge individually or collectively against the directors of this great national work, upon this or upon any other head; but it is undoubtedly adverse to the interests of the proprietors that even the appearance of monopoly or jobbing should be presented to the public, in a work which forms a miracle of art in an age and country in which art has already effected so much.

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[*] The number of persons employed on the works exceed 700.

It cannot escape the notice of the most superficial observer, that in the manufacture of engines, and the other apparatus used upon the road, a singularly exclusive system has been pursued. This system is not less injurious to the ingenious persons themselves who are employed by the directors, than it is to the Company and the public; and it may be hoped that the unequivocal manifestation of public opinion upon the subject, which has been already made, will have the effect of removing or mitigating this evil.

It is not the least evil attending such a state of things, that the genius and enterprise of the country, as far as they may bear upon the improvement of the powers of the undertaking, are paralysed by the distrust, whether well or ill founded, which such a system naturally produces. Those who are skilled to project improvements feel a natural and excusable jealousy, that their proposals will be submitted to the decision of persons who, being competitors in the same race of improvement, are interested in rejecting them; and however pure the motives, and just the judgments, of such arbiters may be, their decisions will never be sanctioned by public confidence. It would, therefore, be wise in the directors of all such bodies, rigorously to exclude from their councils all persons whatever, who directly or *indirectly* receive any advantage from the commerce or manufacture in those objects, the merits of which may be under consideration. *Jobbing* (the bane of British enterprise) should not only be excluded *in reality*, but should be banished even in *appearance*.

(99.) In comparing the extent of capital, and the annual expenditure of the Liverpool and Manchester line, and adopting it as a modulus in estimating the expenses of similar undertakings projected elsewhere, there are several circumstances to which it is important to attend. I have already observed on the large waste of capital in the item of locomotive engines, which ought to be regarded as little more than experimental machines, leading to a rapid succession of improvements. Most of these engines are still in good working order, but have been abandoned for the reasons already assigned. Other companies will, of course, profit by the experience which has been thus purchased at a high price by the Liverpool Company. This advantage in favour of future companies will go on increasing until such companies have their works completed.

A large portion of the current expense of a line of railway is independent of its length; and is little less for the line connecting Liverpool and Manchester, than it would be for a line connecting Birmingham with Liverpool or London.

The establishments of resident engineers, coach and waggon yards, &c. at the extremities of the line, would be little increased by a very great increase in the length of the railway; and the same observation will apply to other heads of expenditure.

It has been the practice of the canal companies between Liverpool and Manchester to warehouse the goods transported between these towns, without any additional charge beyond the price of transport. The Railway Company, in competing with the canals, were, of course, obliged to offer like advantages: this compelled them to invest a considerable amount of capital in the building of extensive warehouses, and to incur the annual expense of porterage, salaries, &c. connected with the maintenance of such storage. In a longer line of railway such expenses (if necessary at all) would not be proportionally increased.

(100.) The comparison of steam-transport with the transport by horses, even when working on a railway, exhibits the advantage of this new power in a most striking point of view. To comprehend these advantages fully, it will be necessary to consider the manner in which animal power is expended as a means of transport. The portion of the strength of a horse available for the purpose of a load depends on the speed of the horse's motion. To this speed there is a certain limit, at which the whole power of the horse will be necessary to move his own body, and at which, therefore, he is incapable of carrying any load; and, on the other hand, there is a certain load which the horse is barely able to support, but incapable of moving with any useful speed. Between these two limits there is a certain rate of motion at which the useful effect of the animal is greatest. In horses of the heavier class, this rate of motion may be taken on the average as that of 2 miles an hour; and in the lighter description of horses, 2½ miles an hour. Beyond this speed, the load which they are capable of transporting diminishes in a very rapid ratio as the speed increases: thus, if 114 express the load which a horse is able to transport a given distance in a day, working at the rate of 4 miles an hour, the same horse will not be able to transport more than the load expressed by 53, *the same distance*, at 7 miles an hour; and, at 10 miles an hour, the load which he can transport will be reduced to 32. The most advantageous speed at which a horse can work being 2 miles an hour, it is found that, at this rate, working for 10 hours daily, he can transport 12 tons, on a level railway, a distance of 20 miles; so that the whole effect of a day's work may be expressed by 240 tons carried 1 mile.

But this rate of transport is inapplicable to the purposes of travelling; and therefore it becomes necessary, when horses are the moving power, to have carriages for passengers distinct from those intended for the conveyance of goods; so that the goods may be conveyed at that rate of speed at which the whole effect of the horse will be the greatest possible; while the passengers are conveyed at that speed which, whatever the cost, is indispensably necessary. The weight of an ordinary mail-coach is about 2 tons; and, on a tolerably level turnpike road, it travels at the rate of 10 miles an hour. At this rate, the number of horses necessary to keep it constantly at work, including the spare horses indispensably necessary to be kept at the several stages, is computed at the rate of a horse per mile. Assuming the distance between London and Birmingham at 100 miles, a mail-coach running between these two places would require 100 horses; making the journey to and from Birmingham daily. The performance, therefore, of a horse working at this rate may be estimated at 2 tons carried 2 miles per day, or 4 tons carried 1 mile in a day. The force of traction on a good turnpike road is at least 12 times its amount on a level rail-road.* It therefore follows, that the performance of a horse on a rail-road will be 12 times the amount of its performance on a common road under similar circumstances. We may, therefore, take the performance of a horse working at 10 miles an hour, on a level rail-road, at 48 tons conveyed 1 mile daily.

The best locomotive engines used on the Liverpool railway are capable of transporting 150 tons on a level rail-road at the same rate; and, allowing the same time for stoppage, its work per day would be 150 tons conveyed 200 miles, or 30,000 tons conveyed 1 mile: from which it follows, that the performance of one locomotive engine of this kind is equivalent to that of 7500 horses working on a good turnpike road, or to 625 horses working on a railway. The consumption of fuel requisite for this performance, with the most improved engines used at present on the Manchester and Liverpool line, would be at the rate of four ounces of coke per ton per mile, including the waste of fuel incurred by the stoppages. Thus the daily consumption of fuel, under such circumstances, would amount to 7500 lbs. of coke; and 1 lb. of coke daily would perform the work of one horse on a good turnpike road; and 12 lbs. of coke daily would perform the work of one horse on a railway.

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* The force of traction on turnpike roads is of course variable. Mr. Gurney considers it to be 20 times the force on a level rail-road.

In this comparison, the engine is taken at its most advantageous speed, while horse-power is taken at its least advantageous speed, if regard be only had to the total quantity of weight transported to a given distance. But, in the case above alluded to, speed is an indispensable element; and steam, therefore, possesses this great advantage over horse-power, that *its most advantageous speed is that which is at once adapted to all the purposes of transport, whether of passengers or of goods.*

The effects of steam compared with horse-power, at lower rates of motion, will exhibit the advantages of the former, though in a less striking degree. An eight-horse waggon commonly weighs 8 tons, and travels at the rate of 2½ miles an hour. Strong horses, working in this way, can travel 8 hours daily; thus each horse performs 20 miles a day. The performance, therefore, of each horse may be taken as equivalent to 20 tons transported 1 mile; and his performance on a railway being 12 times this amount, may be taken as equivalent to 240 tons transported 1 mile a day. The performance of a horse working in this manner is, therefore, 5 times the performance of a horse working at 10 miles an hour; the latter effecting only the performance of 4 tons transported 1 mile per day on a good turnpike road, or 48 tons on a railway. We shall hence obtain the proportion of the performance of horses working in waggons to that of a locomotive steam-engine. Since 1 lb. of coke is equivalent to the daily performance of a horse in a mail-coach, and 12 lbs. on a railway, at 10 miles an hour, it follows that 5 lbs. will be equivalent to the performance of a horse on a turnpike road, and 600 lbs. on a railway, at 2½ miles an hour. Since a locomotive engine can perform the daily work of 7500 mail-coach horses, it follows that it performs the work of 1500 waggon horses.

These results must be understood to be subject to modifications in particular cases, and to be only average calculations. Different steam-engines, as well as different horses, varying in their performance to a considerable extent; and the roads on which horses work being in different states of perfection, and subject to different declivities, the performance must vary accordingly.

In the practical comparison, also, of the results of so powerful an agent as steam applied on railways, with so slight a power as that of horses on common roads, it must be considered that the great subdivision of load, and frequent times of starting, operate in favour of the performance of horses; inasmuch as it would oftener occur that engines capable of transporting enormous weights would start with loads inferior to their power, than would happen in the application of horse-power, where small loads may start at short intervals. This, in fact, constitutes a practical difficulty in the application of steam engines on rail-roads; and will, perhaps, for the present, limit their application to lines connecting places not only of great intercourse with respect to passengers, but also with respect to merchandise.

The most striking effect of steam-power, applied on a rail-road, is the extreme speed of transport which is attained by it; and it is the more remarkable, as this advantage never was foreseen before experience proved it. When the Liverpool and Manchester line was projected, the transport of heavy goods was the object chiefly contemplated; and although an intercourse in passengers was expected, it was not foreseen that this would be the greatest source of revenue to the proprietors. The calculations of future projectors will, therefore, be materially altered, and a great intercourse in passengers will be regarded as a necessary condition for the prosperity of such an undertaking.

If this advantage of speed be taken into account, horse-power can scarcely admit of any comparison whatever with steam-power on a railway. In the experiments which I have already detailed, it appears that a steam engine is capable of drawing 90 tons at the rate of about 20 miles an hour, and that it could transport that weight twice between Liverpool and Manchester in about 3 hours. Two hundred and seventy horses working in waggons would be necessary to transport the same load the same distance in a day. It may be objected, that this was an experiment performed under favourable circumstances, and that assistance was obtained at the difficult point of the inclined plane. In the ordinary performance, however, of the engines drawing merchandise, where great speed is not attempted, the rate of motion is not less than 15 miles an hour. In the trains which draw passengers, the chief difficulty of maintaining a great speed arises from the stoppages on the road to take up and let down passengers. There are two classes of carriages at present used: the first class stops but once, at a point halfway between Liverpool and Manchester, for the space of a few minutes. This class performs the 30 miles in an hour and a half, and frequently in 1 hour and 20 minutes. On the level part of the road its common rate of motion is 27 miles an hour; and I have occasionally marked its rate, and found it fully 30 miles an hour. Indeed, in this respect, the engines seem to have received no great improvement since the opening of the road, unless, perhaps, in their power of maintaining their speed a greater length of time. The engine which conveyed Mr. Huskisson to Manchester, after the unhappy occurrence which took place at the great trial, moved at the rate of 35 miles an hour.

(101.) The quantity of canal property in these countries gives considerable interest to every enquiry, which has for its object the relative advantage of this mode of transport, compared with that of railways, whether worked by horses or by steam-power. Although we shall not here attempt to enter into an exact numerical calculation on this subject, yet there are considerations sufficiently general and obvious to enable us to form a good estimate of the advantages which the railway system possesses over canals, by whatever power either may be worked. The law of the resistance of liquids to bodies moving through them has been long understood, and may be stated generally thus: — If the speed of a body moving through a liquid be increased in a two-fold proportion, the resistance of the liquid to its motion will be increased in more than a four-fold proportion. If the motion be increased in a three-fold proportion, the resistance will be increased in more than a nine-fold proportion, and so on. In fact, if the number which expresses the increased velocity of the body moving through a liquid be multiplied by itself, the product will be less than the corresponding increased resistance. From this it must be very apparent that every effort to obtain a rapid means of transport by canals must be fruitless, whatever power may be employed as the moving principle.* The application of steam engines on a canal, excepting in very rare cases, is impracticable; and even were they applicable, still the resistance would be subject to the same law. It is demonstrable, that no power, however great, is capable of moving a vessel through water with a speed exceeding a certain limit, and that not a very wide one. The most powerful steam engines in the open sea, when unaided by currents or winds, are incapable of propelling a vessel at a more rapid rate than from 10 to 12 miles an hour, but the ordinary rate is considerably less than this.

On the other hand, the resistance arising from the friction on railways is, in no degree, increased by the speed of the motion. A train of carriages moving at the rate of 30 miles an hour offer no more resistance to the moving power, than if the same train were moved at the rate of but 1 mile an hour. The chain or cord which pulls the train suffers the same tension in the one case, and in the other. But this is quite otherwise in the case of a canal, where every increase of speed produces an enormously increased tension in the drawing rope.

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* Some experiments made on the Scottish canals appear to show that boats of a peculiar shape, called gigs, when drawn by horses, do not give a resistance increased according to this law after a velocity of 9 miles an hour has been attained, and that the surge or swell produced by the boat on the canal then ceases. It would appear that in this case the boat rises in a certain degree out of the water, so that the transverse section of the part immersed becomes less. The theory of the resistance being proportional to the square of the velocity supposes that the transverse section of the part immersed remains the same.

I apprehend, however, that the effect alluded to in these experiments would not be produced if the boat were propelled by a steam-engine or any other power *in it*. It seems to be in some degree dependent on the peculiar mode in which the boat is drawn by the power acting on the banks.

(102.) When a very slow rate of travelling is considered, the useful effects of horse-power applied on canals is somewhat greater than the effect of the same power applied on railways; but at all speeds above 3 miles an hour, the effect on railways is greater; and when the speed is considerable, the canal becomes wholly inapplicable, while the railway loses none of its advantages. At 3 miles an hour, the performance of a horse on a canal and a railway is in the proportion of 4 to 3 to the advantage of the canal, but at 4 miles an hour his performance on a railway has the advantage in very nearly the same proportion. At 6 miles an hour, a horse will perform three times more work on a railway than on a canal. At 8 miles an hour, he will perform nearly five times more work.

But the circumstance which must give railways, as compared with canals, an advantage which cannot be considered as less than fatal to the latter, is the fact, that the great speed and cheapness of transit attainable upon a railway by the aid of steam-power will always secure to such lines not only a monopoly of all the travelling, but will increase the actual amount of that source of profit in an enormous proportion, as has been already made manifest between Liverpool and Manchester. Before the opening of the railway there were about 25 coaches daily running between Liverpool and Manchester. If we assume these coaches on the average to take 10 persons at each trip, it will follow that the number of persons passing daily between these towns were about 500. Let us, then, assume that 3000 persons passed weekly. This gives in 6 months 78,000. In the 6 months which terminated on the 31st of December, 1831, the number of passengers between the same towns, exclusive of any taken up on the road, was 256,321; and if some allowance be made for those taken up on the road, the number may be fairly stated at 300,000. At present there is but one coach on the road between Liverpool and Manchester; and it follows, therefore, that, besides taking the monopoly of the transit in travellers, the actual number has been already increased in a four-fold proportion.

The monopoly of the transit of passengers thus secured to the line of communication by rail-road will always yield so large a profit as to enable merchandise to be carried at a comparatively low rate.

In light goods which require despatch it is obvious that the rail-road will always command the preference; and the question between that mode of communication and canals is circumscribed to the transit of those classes of heavy goods in which a small saving in the cost of transport is a greater object than despatch. Even in these classes of goods, the rail-road will command the preference so long as its expenses do not exceed those of the canal.

If the question between *existing* canals and projected rail-roads be one of doubt, much less one in which the advantages of rail-roads preponderate, the question as to which presents more advantages for a *new line of communication* offers little difficulty. We may safely pronounce that, in countries where the arts have arrived at the forward state to which they have attained here, we shall never again see a canal constructed as a means of transport, except in the singular case of connecting two arms of the sea, or two great navigable rivers.

(103.) The first effect which the Liverpool rail-road produced on the Liverpool and Manchester canals was a fall in the price of transport; and at this time, I believe, the cost of transport per ton on the rail-road and on the canals is the same. It will, therefore, be naturally asked, this being the case, why the greater speed and certainty of the rail-road does not in every instance give it the preference, and altogether deprive the canals of transport? This effect, however, is prevented by several local and accidental causes, as well as by direct influence and individual interest. A large portion of the commercial and manufacturing population of Liverpool and Manchester have property invested in the canals, and are deeply interested to sustain them in opposition to the railway. Such persons will give the preference to the canals in their own business, and will induce those over whom they have influence to do so in every case where speed of transport is not absolutely indispensable.

Besides these circumstances, the canal communicates immediately with the shipping at Liverpool, and it ramifies in various directions through Manchester, washing the walls of many of the warehouses and factories for which the goods transported are destined. The merchandise is thus transferred from the shipping to the boat, and brought directly to the door of its owner, or *vice versâ.* If transported by the railway, on the other hand, it must be carried to the station at one extremity; and, when transported to the station at the other, it has still to be carried to its destination in different parts of the town.

These circumstances will sufficiently explain why the canals still retain, and may probably continue to retain, some portion of the traffic between these great marts.

LECTURE XI.

LOCOMOTIVE ENGINES ON TURNPIKE ROADS.

Railways and Turnpike Roads compared — Mr. Gurney's Inventions — His locomotive Steam Engine — Its Performances — Prejudices and Errors — Committee of the House of Commons — Convenience and Safety of Steam Carriages — Hancock's Steam Carriage — Mr. N. Ogle — Trevithick's Invention — Proceedings against Steam Carriages — Turnpike Bills — Steam Carriage between Gloucester and Cheltenham — Its Discontinuance — Report of the Committee of the Commons — Repeal of the prohibitory Bills — Present State and Prospects of Steam Carriages.

(104.) We have hitherto confined our observations to steam-power as a means of transport applied on railways, but modern speculation has not stopped here. Several attempts have been made, and some of them attended with considerable success, to work steam-carriages on turnpike roads. The practicability of this project has been hitherto generally considered to be very questionable; but if we carry back our view to the various epochs in the history of the invention of the steam engine, we shall find the same doubt, and the same difficulty, started at almost every important step in its progress. In comparing the effect of a turnpike road with that of a railway, there are two circumstances which obviously give facility and advantage to the railway. One is, that the obstructions to the rolling motion of the wheels, produced by the inequalities of the surface, are very considerably less on a railway than on a road; less in the proportion of 1 to 12, or, according to some, of 1 to 20. This proportion, however, must depend much on the nature of the road with which the railway is compared. It is obvious, that a well constructed road will offer less resistance than one ill constructed; and it is ascertained that the resistance of a Macadamised road is considerably more than that of a road well paved with stones: the decision of this question, therefore, must involve the consideration of another, viz. whether roads may not be constructed by pavement or otherwise, smoother and better adapted to carriages moved in the manner of steam-carriages than the roads now used for horse power?

But besides the greater smoothness of rail-roads compared with turnpike-roads, they have another advantage, which we suspect to have been considerably exaggerated by those who have opposed the project for steam-carriages on turnpike-roads. One of the laws of adhesion, long since developed by experiment, and known to scientific men, is, that it is greater between the surfaces of bodies of the same nature than between those of a different nature. Thus, between two metals of the same kind it is greater than between two metals of different kinds. Between two metals of any kind it is greater than between metal and stone, or between metal and wood.

Hence, the wheels of steam-carriages running on a rail-road have a greater adhesion with the road, and therefore offer a greater resistance to slip round without the advance of the carriage, than wheels would offer on a turnpike-road; for on a rail-road the iron tire of the wheel rests in contact with the iron rail, while on a common road the iron tire rests in contact with the surface of stone, or whatever material the road may be composed of. Besides this, the dust, and loose matter, which necessarily collect on a common road, when pressed between the wheels and the solid base of the road, act somewhat in the manner of rollers, and give the wheels a greater facility to slip, than if the road were swept clean, and the wheels rested in immediate contact with its hard surface. The truth of this observation is illustrated on the rail-roads themselves, where the adhesion is found to be diminished whenever the rails are covered with any extraneous matter, such as dust or moist clay. Although the adhesion of the wheels of a carriage with a common road, however, be less than those of the wheels of a steam-carriage with a rail-road, yet still the actual adhesion on turnpike-roads is greater in amount than has been generally supposed, and is quite sufficient to propel carriages loaded with considerable weights, and dragging after them loads of large amount.

The relative facility with which carriages are propelled on rail-roads and turnpike-roads equally affects any moving power, whether that of horses or steam-engines; and whether loads be propelled by the one power or the other, the rail-road, as compared with the turnpike-road, will always possess the same proportionate advantage; and a given amount of power, whether of the one kind or the other, will always perform a quantity of work less in the same proportion on a turnpike-road than on a rail-road. But, on the other hand, the expense of original construction, and of maintaining the repairs of a rail-road, is to be placed against the certain facility which it offers to draught.

In the attempts which have been made to adapt locomotive engines to turnpike-roads, the projectors have aimed at the accomplishment of two objects: first, the construction of lighter and smaller engines; and, secondly, increased power. These ends, it is plain, can only be attained, with our present knowledge, by the production of steam of very high temperature and pressure, so that the smallest quantity of water may produce the greatest quantity of steam, and that this quantity of steam shall produce the greatest possible mechanical effect. The methods of propelling the carriage have been in general similar to that used in the rail-road engines, viz. either by the cranks placed on axles, the wheels being fixed upon the same axles, or by connecting piston rods with the spokes of the wheels, as in the engine represented in fig. 55. In some carriages, the boiler and moving power, and the body of the carriage which bears the passengers, are placed on the same wheels. In others, the engine is placed on a separate carriage, and draws after it the carriage which transports the passengers, as is always the case on railways.

The chief difference between the steam-engines used on railways, and those adapted to propel carriages on turnpike-roads, is in the structure of the boiler. In the latter it is essential that while the power remains undiminished, the boiler should be lighter and smaller. The accomplishment of this has been attempted by various contrivances for subdividing a small quantity of water, so as to expose a considerable quantity of surface in contact with it to the action of the fire: spreading the water in thin layers on flat plates; inserting it between plates of iron placed at a small distance asunder, the fire being admitted between the intermediate plates; dividing it into small tubes round which the fire has play; introducing it between the surfaces of cylinders placed one within another, the fire being admitted between the alternate cylinders, have all been resorted to by different projectors.

(105.) First and most prominent in the history of the application of steam to the propelling of carriages on turnpike-roads, stands the name of Mr. GOLDSWORTHY GURNEY, a medical gentleman and scientific chemist, of Cornwall. In 1822, Mr. *Gurney* succeeded Dr. Thompson as Lecturer on Chemistry at the Surrey Institution; and, in consequence of the results of some experiments on heat, his attention was directed to the project of working steam-carriages on common roads, and since 1825 he has unremittingly devoted his exertions and expended his property in perfecting a steam-engine capable of attaining the end he had in view. Numerous other projectors, as might have been expected, have followed in his wake.

Whether they, or any of them, by better fortune, greater public support, or more powerful genius, may outstrip him in the career on which he has ventured, it would not, perhaps, at present, be easy to predict. But whatever be the event, to Mr. *Gurney* is due, and will be paid, the honour of first proving the practicability and advantage of the project; and in the history of the adaptation of the locomotive engine to common roads, his name will stand before all others in point of time, and the success of his attempts will be recorded as the origin and cause of the success of others in the same race.

The incredulity, opposition, and even ridicule, with which the project of Mr. *Gurney* has been met, is very remarkable. His views were from the first opposed by engineers, without one exception. The contracted habit of mind, sometimes produced by an education chiefly, if not exclusively, directed to a merely practical object, subsequently confirmed by exclusively practical pursuits, may, perhaps, in some degree, account for this. But, I confess it has not been without surprise that, I have observed during the last ten years the utter incredulity which has prevailed among men of general science on this subject—an incredulity which the most unequivocal practical proof has scarcely yet dispelled. "Among scientific men," says Mr. *Gurney*, "my opinion had not a single supporter, with the exception of the late Dr. *Wollaston.*"

The mistake which so long prevailed in the application of locomotives on railroads, and which, as we have shown, materially retarded the progress of that invention, was shared by Mr. *Gurney*. Without attempting to reduce the question to the test of experiment, he took for granted, in his first attempts, that the adhesion of the wheels with the road was too slight to propel the carriage. He was assured, he says, by eminent engineers, that this was a point settled by actual experiment. It is strange, however, that a person of his quickness and sagacity did not enquire after the particulars of these "actual experiments." So, however, it was; and, taking for granted the inability of the wheels to propel, he wasted much labour and skill in the contrivance of levers and propellers, which acted on the ground in a manner somewhat resembling the feet of horses to drive the carriage forward. After various fruitless attempts of this kind, the experience acquired in the trials to which they gave rise at last forced the truth upon his notice, and he found that the adhesion of the wheels was not only sufficient to propel the carriage heavily laden on level roads, but was capable of causing it to ascend all the hills which occur on ordinary turnpike roads. In this manner it ascended all the hills between London and Barnet, London and Stanmore, Stanmore Hill, Brockley Hill, and mounted Old Highate Hill, the last at one point rising one foot in nine.

It would be foreign to my present object to detail minutely all the steps by which Mr. *Gurney* brought the locomotive engine which he has invented to its present state of improvement. This, like most other inventions, has advanced towards perfection by a series of partial failures; but it has at length attained that state, in which, if it cannot be regarded as perfect, it is at least profitably available in practice; and by practice alone on an extensive scale can that perfection be obtained, of which this form of engine is certainly susceptible.

(106.) The boiler of Mr. *Gurney* differs in the most striking manner from all other forms of boilers hitherto invented. There is no part of it, not even excepting the grate bars, in which metal exposed to the action of the fire is out of contact with water. If it be considered how rapidly the action of an intense furnace destroys metal when water is not present to prevent the heat from accumulating, the advantage of this circumstance will be appreciated. I have seen the bars of a new grate, never before used, melted in a single trip between Liverpool and Manchester; and the inventor of another form of locomotive engine has admitted to me that his grate bars, though of a considerable thickness, would not last more than a week. In the boiler of Mr. *Gurney*, the grate bars themselves are tubes filled with water, and form, in fact, a part of the boiler itself. This boiler consists of three strong metal cylinders placed in a horizontal position one above the other. A section of the boiler, made by a perpendicular or vertical plane, is represented in fig. 62. The ends of the three cylinders, just mentioned, are represented at D, H and I. In the side of the lowest cylinder D are inserted a row of tubes, a ground plan of which is represented in fig. 63. These tubes proceeding from the side of the lowest cylinder D, are inclined slightly upwards,

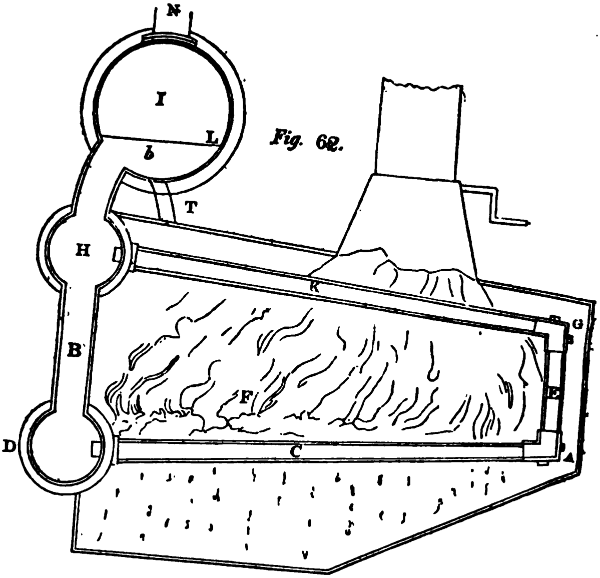
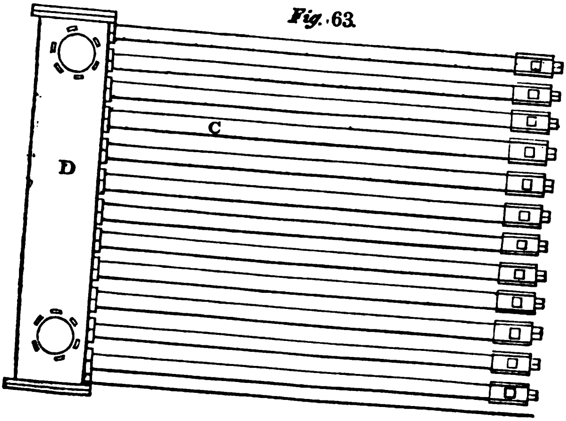


Fig. 62.

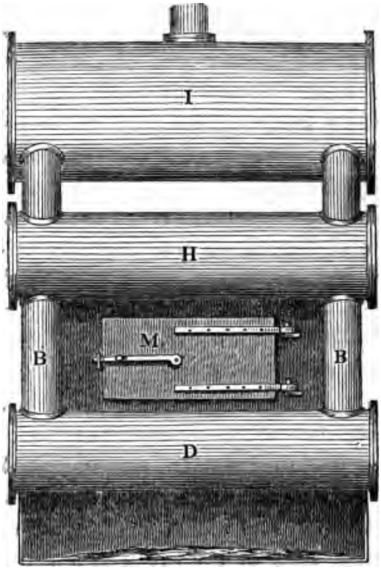
Fig. 63.



for a reason which I shall presently explain. From the nature of the section, only one of these tubes is visible in fig. 62 at C. The other extremities of these tubes at A, are connected with the same number of upright tubes, one of which is expressed at E. The upper extremities G of these upright tubes are connected with another set of tubes K, equal in number, proceeding from G, inclining slightly upwards, and terminating in the second cylinder H.

An end view of the boiler is exhibited in fig. 64,

Fig. 64.



where the three cylinders are expressed by the same letters. Between the cylinders D and H there are two tubes of communication B, and two similar tubes, between the cylinders H and I. From the nature of the section these appear only as a single tube in fig. 62. From the top of the cylinder I proceeds a tube N, by which steam is conducted to the engine.

It will be perceived, that the space F is enclosed on every side by a grating of tubes, which have free communication with the cylinders D and H, which cylinders have also a free communication with each other by the tubes B. It follows, therefore, that if water be supplied to the cylinder I, it will descend through the tubes, and first filling the cylinder D and the tubes C, will gradually rise in the tubes B and E, will next fill the tubes K and the cylinder H. The grating of water pipes C E K forms the furnace, the pipes C being the fire bars, and the pipes E and K being the back and roof of the stove. The fire-door, for the supply of fuel, appears at M, fig. 64. The flue issuing between the tubes F, is conducted over the tubes K, and the flame and hot air is carried off through a chimney. That portion of the heat of the burning fuel, which in other furnaces destroys the bars of the grate, is here expended in heating the water contained in the tubes C. The radiant heat of the fire acts upon the tubes K, forming the roof of the furnace, on the tubes E at the back of it, and partially on the cylinders D and H, and the tubes B. The draft of hot air and flame passing into the flue at A, acts upon the posterior surfaces of the tubes E, and the upper sides of the tubes K, and finally passes into the chimney.

As the water in the tubes C E K is heated, it becomes specifically lighter than water of a less temperature, and consequently acquires a tendency to ascend. It passes, therefore, rapidly into H. Meanwhile the colder portions descend and the inclined positions of the tubes C and K give play to this tendency of the heated water, so that a prodigiously rapid circulation is produced, when the fire begins to act upon the tubes. When the water acquires such a temperature that steam is rapidly produced, steam bubbles are constantly formed in the tubes surrounding the fire, and if these remained stationary in the tubes the action of the fire would not only decompose the steam but render the tubes red hot, the water not passing through them to carry off the heat. But the inclined position of the tubes, already noticed, effectually prevents this injurious consequence. A steam bubble which is formed either in the tubes C or K, having a tendency to ascend proportional to its lightness as compared with water, necessarily rushes upwards, if in C towards A, and if in K towards H. But this motion of the steam is also aided by the rapid circulation of the water which is continually maintained in the tubes, as already explained, otherwise it might be possible, notwithstanding the levity of steam compared with water, that a bubble might remain in a narrow tube without rising. I notice this more particularly, because the burning of the tubes is a defect which has been erroneously, in my opinion, attributed to this boiler. To bring the matter to the test of experiment, I have connected two cylinders, such as D and H, by a system of glass tubes, such as represented at C E K. The rapid and constant circulation of the water was then made evident: bubbles of steam were formed in the tubes, it is true; but they passed with inconceivable rapidity into the upper cylinder, and rose to the surface, so that the glass tubes never acquired a higher temperature than that of the water which passed through them.

This, I conceive, to be the cardinal excellence of Mr. *Gurney's* boiler. It is impossible that any part of the metal of which it is formed can receive a greater temperature than that of the water which it contains, and that temperature, as is obvious, can be regulated with the most perfect certainty and precision. I have seen the tubes of this boiler, while exposed to the action of the furnace, after that action has continued for a long period of time, and I have never observed the soot which covers them to redden, as it would do if the tube attained a certain temperature.

Every part of this boiler being cylindrical, it has the form which, mechanically considered, is most favourable to strength, and which, within given dimensions, contains the greatest quantity of water. It is also free from the defects arising from unequal expansion, which are found to be most injurious in tubular boilers. The tubes C and K can freely expand in the direction of their length, without being loosened at their joints, and without straining any part of the apparatus; the tubes E being short, are subject to a very slight degree of expansion, and it is obvious that the long tubes, with which they are connected, will yield to this without suffering a strain, and without causing any part of the apparatus to be loosened. This is an advantage which will be rendered more apparent by referring to the defect already pointed out in the boilers used on the Liverpool and Manchester railway.

When water is converted into steam, any foreign matter which may be combined with it is disengaged, and is deposited on the bottom of the vessel in which the water is evaporated. All boilers, therefore, require occasional cleansing, to prevent the crust thus formed from accumulating; and this operation, for obvious reasons, is attended with peculiar difficulty in tubular boilers. In the case before us, the crust of deposited matter would gather and thicken in the tubes C and K, and if not removed, would at length choke them. But besides this, it would be attended with a still worse effect; for, being a bad conductor, it would intercept the heat in its transit from the fire to the water, and would cause the metal of the tube to become unduly heated. Mr. *Gurney* of course foresaw this inconvenience, and contrived an ingenious chemical method of removing it, by occasionally injecting through the tubes such an acid as would combine with the deposit, and carry it away. This method was perfectly effectual, and although its practical application was found to be attended with difficulty in the hands of common workmen, Mr. *Gurney* was persuaded to adhere to it by the late Dr. *Wollaston*, until experience proved the impossibility of getting it effectually performed, under the circumstances in which boilers are commonly used. Mr. *Gurney* then adopted the more simple, but not less effectual, method of removing the deposit by mechanical means. Opposite the mouths of the tubes, and on the other side of the cylinders D and H, are placed a number of holes, which, when the boiler is in use, are stopped by pieces of metal screwed into them. When the tubes require to be cleaned these stoppers are removed, and an iron scraper is introduced through the holes into the tubes, which, being passed backwards and forwards, easily and completely removes the deposit. The boiler may be thus cleaned by a common labourer in half a day, at an expense of about 1*s.* 6*d.*

The frequency of the periods at which a boiler of this kind requires cleaning must depend, in a great degree, on the nature of the water which is used: one in daily use with the water of the river Thames would not require cleaning more than once in a month; but with water of the most unfavourable description, once a fortnight would be sufficient.

(107.) In the more recent boilers constructed by Mr. *Gurney*, he has maintained the draught through the furnace, by the method of projecting the waste steam into the chimneys; a method so complete and so perfectly effectual, that it is extremely unlikely to be superseded by any other. The objection which has been urged against it in locomotive engines, working on turnpike roads, is, that the noise which it produces has a tendency to frighten horses.

The defect on which this objection is founded has been long since removed by Mr. *Gurney*. In the engines on the Liverpool road, the steam is allowed to pass directly from the eduction pipe of the cylinder to the chimney, and it there escapes in puffs corresponding with the alternate motion of the pistons, and produces a noise, which, although attended with no inconvenience on the rail-road, would certainly be objectionable on turnpike-roads. In the engine used in Mr. *Gurney's* steam-carriage, the steam which passes from the cylinders is conducted to a receptacle, which he calls a blowing box. This box serves the same purpose as the upper chamber of a smith's bellows. It receives the steam from the cylinders in alternate puffs, but lets it escape into the chimney in a continued stream by a number of small jets. A more powerful draught is by this means produced, and no noise is perceived. Another exit for the steam is also provided, by which the conductor is enabled to increase or diminish, or to suspend altogether, the draught in the chimney, so as to adapt the intensity of the fire to the exigencies of the road. This is a great convenience in practice, because, on some roads, a draught is scarcely required, while on others, a powerful blast is indispensable.

Connected with this blowing box, is another ingenious apparatus of considerable practical importance. The pipe through which the water which feeds the boiler is conducted to it from the tank is carried through this blowing box, within which it is coiled in a spiral form, so that an extensive thread of the feeding water is exposed to the heat of the waste steam, which has escaped from the cylinders, and which is enclosed in this blowing-box. In passing through this pipe the feeding water is raised from the ordinary temperature of about 60° to the temperature of 212°. The fuel necessary to accomplish this is, therefore, saved, and the amount of this is calculated at 1-6th of all that is necessary to evaporate the water. Thus, 1-6th of the expense of fuel is saved. But what is much more important in a locomotive-engine, 1-6th of the weight of the engine is saved without any sacrifice of its power. There is still another great advantage attending this process. The feeding water in the worm just mentioned, while it takes up the heat from the surrounding steam in the blowing-box condenses 1-6th of the waste steam, which is thence conducted to the tank, from which the feeding water is pumped, saving in this manner 1-6th in weight and room of the water necessary to be carried in the carriage for feeding the boiler.*

So far as the removal of all inconvenience arising from noise, this contrivance has been proved by experience to be perfectly effectual.†

In all boilers, the process of violent ebullition causes a state of agitation in the water, and a number of counter currents, by which, as the steam is disengaged from the surface of the water, it takes with it a considerable quantity of water in mechanical mixture. If this be carried through the cylinders, since it possesses none of the qualities of steam, and adds nothing to the power of the vapour with which it is combined, it causes an extensive waste of heat and water, and produces other injurious effects. In every boiler, therefore, some means should be provided for the separation of the water thus suspended in the steam, before the steam is conducted to the cylinder. In ordinary plate boilers, the large space which remains above the surface of the water serves this purpose. The steam being there subject to no agitation or disturbance, the water mechanically suspended in it descends by its own gravity, and leaves pure steam in the upper part. In small tubular boilers, this has been a matter, however, of greater difficulty. The contracted spaces in which the ebullition takes place, causes the water to be mixed with the steam in a greater quantity than could happen in common plate boilers: and the want of the same steam-room renders the separation of the water from the steam a matter of some difficulty. These inconveniences have been, of course, encountered by Mr. *Gurney*; and they have been overcome by a succession of contrivances of great mechanical felicity. I have already described the rapid and regular circulation effected by the arrangement of the tubes. By this a regularity in the currents is established, which alone has a tendency to diminish the mixture of water with the steam. But in addition to this, a most effectual method of separation is provided in the vessel I, which is a strong iron cylinder of some magnitude, placed out of the immediate influence of the fire. A partial separation of the steam from the water takes place in the cylinder H; and the steam with the water mechanically suspended in it, technically called moist steam, rises into the *separator* I. Here, being free from all agitation and currents, and being, in fact, quiescent, the particles of water fall to the bottom, while the pure stream remains at the top. This separator, therefore, serves all the purposes of the steam-room, above the surface of the water in the large plate-boilers. The dry steam is thus collected and ready for the supply of the engine through the tube N, while the water, which is disengaged from it, is collected at the bottom of the separator, is conducted through the tube T to the lowest vessel D, to be again circulated through the boiler.

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* In boilers constructed for stationary purposes, or for steam navigation, the steam-pipe, after it has passed through the blowing box is continued and made to form a series of returned flues over the boiler, so as to take up the waste heat after it has passed the boiler, and before it reaches the chimney. But in loco-motive engines for common roads, it has been found by experience, that the power gained by the waste heat is not sufficient to propel the weight of the material necessary for taking it up.

† See Report of the Commons.

The pistons of the engine work on the axles of the hind wheels of the carriage which bears the engine, by cranks, as in the locomotives on the Manchester railway, so that the axle is kept in a constant state of rotation while the engine is at work. The wheels placed on this axle are not permanently fixed or keyed upon it, as in the Manchester locomotives; but they are capable of turning upon it in the same manner as ordinary carriage wheels. Immediately within these wheels there are fixed upon the axles two projecting spokes or levers, which revolve with the axle, and which take the position of two opposite spokes of the wheel. These may be occasionally attached to the wheel or detached from it, so that they are capable of compelling the wheels to turn with the axle, or leaving the axle free to turn independent of the wheel, or the wheel independent of the axle, at the pleasure of the conductor. It is by these levers that the engine is made to propel either or both of the wheels. If both pair of spokes are thrown into connection with the wheels, the crank shaft or axle will cause both wheels to turn with it, and in that case the operation of the carriage is precisely the same as those of the locomotives already described upon the Liverpool and Manchester line; but this is rarely found to be necessary, since the adhesion of one wheel with the road is generally sufficient to propel the carriage, and consequently only one pair of these fixed levers are generally used, and the carriage propelled by only one of the two hind wheels. The fore wheels of the carriage turn upon a pivot similar to those of a four-wheeled coach. The position of these wheels is changed at pleasure by a simple pinion and circular rack, which is moved by the conductor, and in this manner the carriage is guided with precision and facility.

The force of traction necessary to propel a carriage upon common roads must vary with the variable quality of the road, and consequently the propelling power, or the pressure upon the pistons of the engine, must be susceptible of a corresponding variation; but a still greater variation becomes necessary from the undulations and hills which are upon all ordinary roads. This necessary change in the intensity of the impelling power is obtained in Mr. *Gurney's* engine by restraining the steam in the boiler by the throttle valve, as already described in the locomotive engines on the railroad. This principle, however, is carried much further in the present case. The steam in the boiler may be at a pressure of from 100 to 200 lbs. on the square inch; while the steam on the working piston may not exceed 30 or 40lbs. on the inch. Thus an immense increase of power is always at the command of the conductor; so that when a hill is encountered, or a rough piece of road, he is always enabled to lay on power sufficient to meet the exigency of the occasion.

The two difficulties which have been always apprehended in the practical working of steam carriages upon common roads are, first, the command of sufficient power for hills and rough pieces of road; and, secondly, the apprehended insufficiency of the adhesion of the wheels with the road to propel the carriage. The former of these difficulties has been completely overcome by the nature of Mr. *Gurney's* boiler, allowing steam of very great pressure to be constantly maintained in it with perfect safety. As to the second, all his experiments tend to show that there is no ground for the supposition that the adhesion of the wheels are in any case insufficient for the purposes of propulsion. He states, that he has succeeded in driving carriages thus propelled up considerable hills on the turnpike roads about London. He made a journey to Barnet with only one wheel attached to the axle, which was found sufficient to propel the carriage up all hills upon that road. The same carriage, with only one propelling wheel, also went to Bath, and surmounted all the hills between Cranford Bridge and Bath, going and returning.

A double stroke of the piston produces one revolution of the propelling wheels, and causes the carriage to move through a space equal to the circumference of those wheels. It will therefore be obvious, that the greater the diameter of the wheels the better adapted the carriage is for speed; and, on the other hand, wheels of a smaller diameter are better adapted for power. In fact, the propelling power of an engine on the wheels will be in the inverse proportion of their diameter. In carriages designed to carry great weights at a moderate speed, smaller wheels will be used; while in those intended for the transport of passengers at considerable velocities, wheels of 5 feet diameter are most advantageous.

Among the numerous popular prejudices to which this new invention has given rise, one of the most mischievous in its effects and most glaring in its falsehood, is the notion that carriages thus propelled are more injurious to roads than carriages drawn by horses. This error has been most clearly and successfully exposed in the evidence taken before the committee of the House of Commons upon steam carriages. It is there fully demonstrated, not only that carriages thus propelled do not wear a turnpike road more rapidly than those drawn by horses, but that, on the other hand, the wear by the feet of horses is far more rapid and destructive than any which could be produced by the wheels of carriages. Steam carriages admit of having the tires of the wheels broad, so as to act upon the road more in the manner of rollers, and thereby to give consistency and firmness to the material of which the road is composed. The driving wheels being fully proved not to slip upon the road, do not produce any effects more injurious than the ordinary rolling wheels; consequently the wear occasioned by a steam carriage upon a road is not more than that produced by a carriage drawn by horses of an equivalent weight and the same or equal tires; but the wear produced by the pounding and digging of horses' feet in draught is many times greater than that produced by the wear of any carriage. Those who still have doubts upon this subject, if there be any such persons, will be fully satisfied by referring to the evidence which accompanies the report of the committee of the House of Commons, printed in October, 1831. In that report they will not only find demonstrative evidence that the introduction of steam carriages will materially contribute to the saving in the wear of turnpike roads, but also that the practicability of working such carriages with an immense saving to the public — with a great increase of speed and other conveniences to the traveller — is fully established.

The weight of machinery necessary for steam carriages is sometimes urged as an objection to their practical utility. Mr. *Gurney* states, that, by successive improvements in the details of the machinery, the weight of his carriages, without losing any of the propelling power, has been reduced to 35 cwt., exclusive of the load, and exclusive of the fuel or water: but thinks that it is possible to reduce the weight still further. He has a carriage now in process of construction, the weight of which he expects will not exceed 5 cwt., and which he considers will do the work of one horse, and carry two or three passengers. In this particular machine speed is the principal object. The diameter of the propelling wheels should be 5 feet, with a breadth of tire of about 3½ inches. A steam carriage constructed by Mr. *Gurney*, weighing 35 cwt., working for 8 hours, is found, according to his statement, to do the work of about 30 horses. He calculates that the weight of his propelling carriage, which would be capable of drawing 18 persons, would be equal to the weight of 4 horses; and the carriage in which these persons would be drawn would have the same weight as a common stage coach capable of carrying the same number of persons. Thus the weight of the whole — the propelling carriage and the carriage for passengers taken together — would be the same with the weight of a common stage coach, with 4 horses inclusive.

(108.) There are two methods of applying locomotives upon common roads to the transport of passengers or goods; the one is by causing the locomotive to carry, and the other to draw the load, and different projectors have adopted the one and the other method. Each is attended with its advantages and disadvantages. If the same carriage transport the engine and the load, the weight of the whole will be less in proportion to the load carried; also a greater pressure may be produced on the wheels by which the load is propelled. It is also thought that a greater facility in turning and guiding the vehicle, greater safety in descending hills, and a saving in the original cost, will be obtained. On the other hand, when the passengers are placed in the same carriage with the engine, they are necessarily more exposed to the noise of the machinery and to the heat of the boiler and furnace. The danger of explosion is so slight, that, perhaps, it scarcely deserves to be mentioned; but still *the apprehension* of danger on the part of the passengers, even though groundless, should not be disregarded. This apprehension will be obviously removed or diminished by transferring the passengers into a carriage separate from the engine; but the greatest advantage of keeping the engine separate from the passengers is the facility which it affords of changing one engine for another in case of accident or derangement on the road, in the same manner as horses are changed at the different stages: or, if such an accident occur in a place where a new engine cannot be procured, the load of passengers may be carried forward by horses, until it is brought to some station where a locomotive may be obtained. There is also an advantage arising from the circumstance that when the engines are under repair, or in process of cleaning, the carriages for passengers are not necessarily idle. Thus the same number of carriages for passengers will not be required when the engine is used to draw as when it is used to carry.

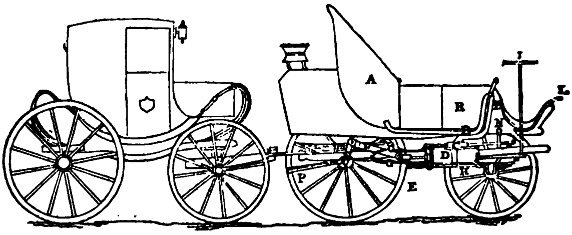
In case of a very powerful engine being used to carry great loads, it would be quite impracticable to place the engine and loads on four wheels, the pressure being such as no turnpike road could bear. In this case it would be indispensably necessary to place a part of the load at least upon separate carriages to be drawn by the engine.

In the comparison of carriages propelled by steam with carriages drawn by horses, there is no respect in which the advantage of the former is so apparent as the safety afforded to the passenger. Steam power is under the most perfect control, and a carriage thus propelled is capable of being guided with the most admirable precision. It is also capable of being stopped almost suddenly, whatever be its speed; it is capable of being turned within a space considerably less than that which would be necessary for four-horse coaches. In turning sharp corners, there is no danger with the most ordinary care on the part of the conductor. On the other hand, horse power, as is well known, is under very imperfect control, especially when horses are used adapted to that speed which at present is generally considered necessary for the purposes of travelling. "The danger of being run away with and overturned," says Mr. *Farey*, in his evidence before the House of Commons, "is greatly diminished in a steam coach. It is very difficult to control four such horses as can draw a heavy stage coach 10 miles an hour, in case they are frightened or choose to run away; and, for such quick travelling, they must be kept in that state of courage that they are always inclined to run away, particularly down hill, and at sharp turns in the road. Steam power has very little corresponding danger, being perfectly controllable, and capable of exerting its power in reverse to retard in going down hill. It must be carelessness that would occasion the overturning of a steam carriage. The chance of breaking down has been hitherto considerable, but it will not be more than in stage coaches when the work is truly proportioned and properly executed. The risk from explosion of the boiler is the only new cause of danger, and that I consider not equivalent to the danger from horses."

That the risk of accident from explosion is very slight indeed, if any such risk exists, may be proved from the fact that the boilers used on the Liverpool and Manchester rail-road being much larger, and in proportion, inferior in strength to those of Mr. *Gurney's*, and other steam carriage projectors, have never yet been productive of any injurious consequences by explosion, although they have frequently burst. I have stood close to a locomotive on the rail-road when the boiler burst. The effect was that the water passed through the tubes into the fire and extinguished it, but no other consequence ensued.

In fig. 65. is represented the appearance of a locomotive of Mr. *Gurney's*, drawing after it a carriage for passengers.

Fig. 65

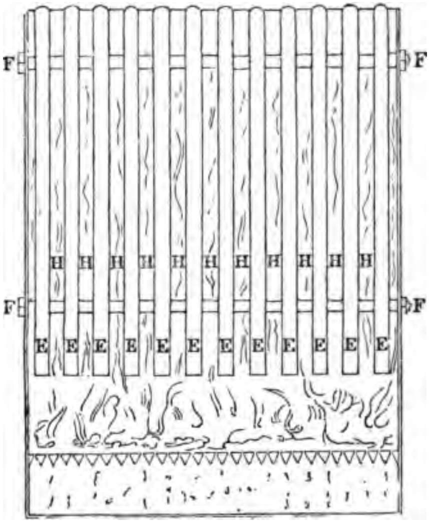


(109.) One of the greatest difficulties which locomotives upon a turnpike road have to encounter, is the ascent of very steep hills, for it is agreed upon all hands that hills of very moderate inclinations present no difficulty which may not be easily overcome, even in the present state of our knowledge. The fact of Mr. *Gurney* having propelled his carriage up old Highgate Hill, when the apparatus was in a much more imperfect state than that to which it has now attained, establishes the mere question of the possibility of overcoming the difficulty; but it remains still to be decided whether the inconvenience caused by providing means of meeting the exigency of very steep hills may not be greater than the advantage of being able to surmount them can compensate for: and Mr. *Farey*, whose authority upon subjects of this kind is entitled to the highest respect, thinks that it is upon the whole more advantageous to provide at very steep hills, post horses to assist the steam-carriage up them, than to incur the inconvenience of providing the necessary power and strength of machinery for occasions which at best but rarely occur. If the question merely referred to the command of motive power, it appears to me that Mr. *Gurney's* boiler would be amply sufficient to supply all that could be required for any hills which occur upon turnpike roads; but it is not to be forgotten, that not merely an ample supply of motive power, but also a strength and weight in the machinery proportionate to the power to be exerted is indispensably necessary. The strength and weight necessary to ascend a very steep hill will be considerably greater than that which is necessary for a level road, or for hills of moderate inclinations; and it follows that if we ascend those steep hills by the unaided power of the locomotive, we must load the engine with all the weight of machinery requisite for such emergencies, such additional weight being altogether unnecessary, and therefore a serious impediment upon all other parts of the road, inasmuch as it must exclude an equivalent weight of goods or passengers, which might otherwise be transported, and thereby in fact diminish proportionally the efficiency of the machine. It is right, however, to observe, that this is a point upon which a difference of opinion is entertained by persons equally competent to form a judgment, and that some consider that it is practicable to construct an engine without inconvenient weight which will ascend all the hills which occur upon turnpike roads.

However this may be, the difficulty is one which the improved system of roads in England renders of a comparatively trifling nature. If horses were resorted to as the means of assistance up such hills as the engine would be incapable of surmounting, such aid would not be requisite more than twice or thrice upon the mail-coach road between London and Holyhead; and the same may be said of the roads connecting the greatest points of intercourse in the kingdom. Such hills as the ascent at Pentonville upon the New Road, the ascent in St. James's Street, the ascent from Waterloo Place to the County Fire Office, the ascent at Highgate Archway, present no difficulty whatever. It is only Old Highgate Hill, and hills of a similar kind, which would ever require a supply of horses in aid of the engine. I therefore incline to agree with Mr. *Farey*, that, at least for the present, it will be more expedient to construct carriages adapted to surmount moderate hills only, and to provide post horses in aid of the extreme emergencies to which I have just alluded.

(110.) In the boiler to be used in the steam-carriage projected by Mr. *Walter Hancock*, the subdivision of the water is accomplished by dividing a case or box by a number of thin plates of metal, like a galvanic battery, the water being allowed to flow between every alternate pair of plates, at E, fig. 66. and the intermediate spaces H forming the flue through which the flame and hot air are propelled.

Fig. 66.



In fact, a number of thin plates of water are exposed on both sides to the most intense action of flame and heated air; so that steam of a high pressure is produced in great abundance and with considerable rapidity. The plates forming the boiler are bolted together by strong iron ties, extending across the boiler, at right angles to the plates, as represented in the figure The distance between the plates is 2 inches.

There are ten flat chambers of this kind for water, and intermediately between them ten flues. Under the flues is the fireplace, or grate; containing 6 square feet of fuel in vivid combustion. The chambers are all filled to about two thirds of their depth with water, and the other third is left for steam. The water-chambers, throughout the whole series, communicate with each other both at top and bottom, and are held together by two large bolts. By releasing these bolts, at any time, the chambers fall asunder; and, by screwing them up, they may be all made tight again. The water is supplied to the boiler by a forcing-pump, and the steam issues from the centre of one of the flues at the top.

These boilers are constructed to bear a pressure of 400 or 500 lbs. on the square inch; but the average pressure of the steam on the safety valve is from 60 to 100. There are 100 square feet of surface in contact with the water exposed to the fire. The stages which such an engine performs are 8 miles, at the end of which a fresh supply of fuel and water are taken in. It requires about 2 bushels of coke for each stage.

The steam-carriage of Mr. *Hancock* differs from that of Mr. *Gurney* in this, — that, in the former, the passengers and engine are all placed on the same carriage. The boiler is placed behind the carriage; and there is an engine-house between the boiler and the passengers, who are placed in the fore part of the vehicle; so that all the machinery is behind them. The carriages are adapted to carry 14 passengers, and weigh, exclusive of their load, about 3½ tons, the tires of the wheels being about 3½ inches in breadth. Mr. *Hancock* states, that the construction of his boiler is of such a nature, that, even in the case of bursting, no danger is to be apprehended, nor any other inconvenience than the stoppage of the carriage. He states, that, while travelling about 9 miles an hour, and working with a pressure of about 100 lbs. on the square inch, loaded with 13 passengers, the carriage was suddenly stopped. At first the cause of the accident was not apparent; but, on opening one of the cocks of the boiler, it was found that it contained neither steam nor water. Further examination proved that the boiler had burst. On unscrewing the bolts, it was found that there were several large holes in the plates of the water-chamber, through which the water had flowed on the fire; but neither noise nor explosion, nor any dangerous consequences ensued.

This boiler, as compared with that of Mr. *Gurney's*, has some obvious defects. It is evident that thin flat plates are the form which, mechanically considered, is least favourable to strength; nor does it appear that any material advantage is gained to compensate for this by the magnitude of the surface exposed to the action of the fire. It is a great defect that a part of the surface of each of the plates is exposed to the action of the fire while it is out of contact with the water; in fact, in the upper part of the spaces marked E, fig. 66. steam only is contained. It has been observed by engineers, and usually shown by experiment, that if steam be heated on the surface of water, it will be decomposed, and its elasticity destroyed; this is not the only evil connected with the arrangement, for on this part of the metal, nevertheless, the fire acts — with less intensity, it is true, than on that part which contains the water, — but still with sufficient intensity to destroy the metal. Mr. *Hancock* appears to have attempted to remedy this defect by occasionally inverting the position of the flat chambers, placing that which at one time was at the bottom at the top, and *vice versâ*. This, may equalise the wear produced by the action of the fire upon the metal out of contact with water, but still the wear on the whole will not be less rapid. There appears to be no provision or space for separating the steam from the water with which it is charged; in fact, there are no means in this engine of discharging the function of Mr. *Gurney's* separator. This will be found to produce considerable waste and loss of power in practice.

The bars upon which the fire rests are of solid metal, and such is the intense heat to which they are subject, that, in an engine constantly at work, it is impossible that they can last, without being renewed, more than about a week, if so much. The draft is maintained in this engine by means of a revolving fan worked by the engine. This, perhaps, is one of the greatest defects as compared with other locomotives. The quantity of power requisite to work this bellows, and of which the engine is robbed, is very great—so great as to amount to perhaps more than half the whole working power of the machine. This defect is so fatal, that I consider it is quite impossible that the ingenious inventor can persevere in the use of it. Mr. *Hancock* has abandoned the use of the cranks upon his working axle, and has substituted an endless chain and rag-wheels. This also appears to me defective, and a source by which considerable power is lost. On the other hand, however, the weakness of the axle which is always produced by cranks is avoided.

Mr. *Hancock* is now employed in preparing carriages which he intends to work upon the New Road, between Paddington and the Bank, and other roads in the immediate neighbourhood of London.

(111.) Mr. *Nathaniel Ogle*, of Southampton, states, that he has constructed a locomotive carriage, under a patent; and has for some time been employed in working it experimentally. I have not had an opportunity of seeing drawings of this machine. The following description, however, is taken from the evidence of Mr. *Ogle* before a committee of the House of Commons.

> " Our experimental vehicle, weighing about 3 tons, or rather more, we have propelled from London to Southampton, and on the roads in the vicinity of Millbrook, at various speeds. The greatest velocity we obtained, over rather a wet road, with patches of gravel upon it, was between 32 and 35 miles an hour; this might have been continued under similar circumstances, and we could, on a good road, have increased that speed to 40 miles. We have ascended a hill with a soft wet bottom, rising one foot in six, at rather a slow rate. We have ascended one of the loftiest hills in the district near Southampton, at 16½ miles an hour. We have gone from the turnpike-gate at Southampton to the four mile stone on the London road, — a continued elevation, with one very slight descent, — at a rate of 24½ miles an hour, loaded with people.
>
> " The base of the boiler and the summit are composed of cross pieces, cylindrical within and square without; there are holes bored through these cross pieces, and inserted through the whole is an air tube. The inner hole of the lower surface, and the under hole of the upper surface, are rather larger than the other ones. Round the air tube is placed a small cylinder, the collar of which fits round the larger aperture on the inner surface of the lower frame, and the under surface of the upper framework. These are both drawn together by screws from the top; these cross pieces are united by connecting pieces, the whole strongly bolted together; so that we obtain, in one tenth of the space, and with one tenth of the weight, the same heating surface and power as is now obtained in other and low-pressure

boilers, with incalculably greater safety. Our present experimental boiler contains 250 superficial feet of heating surface in the space of 3 feet 8 inches high, 3 feet long, and 2 feet 4 inches broad, and weighs about 8 cwt. We supply the two cylinders with steam, communicating by their pistons with a crank axle, to the ends of which either one or both wheels are affixed, as may be required. One wheel is found to be sufficient, except under very difficult circumstances, and when the elevation is about one foot in six, to impel the vehicle forward.

" The cylinders of which the boiler is composed are so small, as to bear a greater preſsure than could be produced by the quantity of fire beneath the boiler; and if any one of these cylinders should be injured by violence, or any other way, it would become merely a safety valve to the rest. We never, with the greatest pressure, burst, rent, or injured our boiler; and it has not once required cleaning, after having been in use twelve months."

(112.) The last contrivance which we shall here describe for locomotive boilers is that of the original inventor of locomotive engines, Mr. *Trevithick*. The following is extracted from the Report of the Committee of the House of Commons already alluded to: —

" I have made an entire new engine, both in principle and arrangements; the fire-place, boiler, and condenser, are formed of six wrought-iron tubes, standing perpendicular on their ends, encircled the one within the other for the purpose of safety, and to occupy little room, also for keeping the boiler to one constant gauge, with fine distilled water, permanently working without loss, by condensing the steam and never suffering it to escape out of the engine, but returning it from the condenser back again into the boiler, every stroke of the engine, by a force-pump: and, where an engine is perfectly tight, it would work for ever without a replenish of water; but, to supply leaks, a small evaporating apparatus is used for supplying the deficiency with distilled water, which effectually prevents any fluctuation in the height of water in the boiler, or collecting sediment, and an impossibility of ever getting the boiler red-hot, there being no space for the water to fly to out of the boiler but into the condenser; and this is so small, that if by any means the force-pump did not return the water regularly from the condenser to the boiler, the space in the condenser, by taking 1 inch in depth of water out of the boiler, would fill and glut the condenser, so that the engine would stand still; and, as the water cannot diminish, it does not require a large quantity of water or water space in the boiler, so necessary in other engines, to guard against fluctuation in the feed, and prevent the boiler becoming red-hot. The boiler being considerably less, the strength and room will be increased; and, never getting hot, the engine might be worked with much higher steam; if so high as gas-holders are charged with, theory gives the saving of fuel, weight, and room over low-pressure engines of 16 to 1, without requiring a supply of water. I state this to show the probable advantages which will arise from this new engine. For my engine to be 100 horse power, to raise sufficient steam, the fire tube must be 3 feet diameter, which would give the boiler a diameter of 3 ft. 8 in. and that a half inch thick, according to the theory of the strength of iron, would sustain a pressure of 1736 lbs. to the inch, which is four times as great as the pressure which gas-holders are charged with, and thirty-two times the pressure that the high-pressure engines work with at present; which is still further proof that the explosions have been solely occasioned by the boilers being under water-gauge, and heated red-hot. If, after boilers have been forced on their trial by a cold water pressure, to stand ten times the pressure that they are to be worked at, and a boiler should happen to explode, the shock would be first received by the next surrounding tube, and so on for six successive surrounding tubes; each space between the tubes would admit the steam to escape up the chimney gently without harm, and the outside tube that encircles the whole might be made of three quarters of an inch thick, so that it would put injury from explosion beyond possibility.

" The arrangements of this new engine embrace every advantage that can be wished for;— safety, saving of fuel, lightness, little room, cheapness, simplicity, and being nearly independent of water."

At the moment that this work is going to press, I have been favoured with a view of the drawings and model of a steam-carriage, invented by Dr. *Church* of Birmingham. The specifications for his patent, however, not being yet completed, I cannot with propriety make public any detailed description of the machine. I may, however, state generally, that the boiler is tubular, the water being contained between two tubes, one placed within the other, so that a number of thin cylindrical shells of water are exposed, both on their concave and convex surfaces to the action of the fire. In fact, the interior of these tubes form the flues of the furnace. A considerable number of such tubes are placed in a vertical position, surrounding a circular fire-place. They are in the form of siphons, to counteract the injurious effects of unequal expansion. The draught is produced by a fanner worked by the engine, and the furnace is made to consume its own smoke.

The crank-shaft, worked by the cylinders, is connected by endless chains with the axles of the hind wheels of the carriage, and it is a peculiarity in this machine, that those two wheels have separate axles. The springs of the machine are, in fact, the spokes of the wheels, which are so contructed as to combine strength and lightness, and at the same time to possess all the elasticity necessary to equalise the unevenness of the road. The passengers and engine are placed on the same carriage, which is constructed to accommodate about 50 passengers. The tires of the wheels are almost 6 inches in breadth, and it is proposed to make the working wheels 8 feet in diameter.

A company has been formed for the purpose of working Dr. *Church*'s carriages on the road between London, Birmingham, Manchester, and Liverpool.

(113.) After the statement which I have here made of the power and efficiency of some of the locomotive engines, proposed to be adapted to turnpike roads, it will naturally be asked how far these schemes have been realised, and whether, in any instances, such carriages have been brought into practical operation? It is a matter of regret that such an enquiry cannot be answered without at the same time admitting, that, abundant as is the capital, and great the enterprise of this country, there still remains in it bigotry, ignorance, and dishonesty, which, at the instigation of self-interest, and other unworthy motives, are frequently arrayed in opposition to the progress of every improvement; and, although that progress be ultimately certain and inevitable, still such impediments will obstruct and retard its course for a time. In the case of projectors of steam-carriages, we have witnessed a system of interested and ignorant persecution which would disgrace a nation 500 years behind Great Britain in civilisation. In the early part of the year 1831, a carriage was established by Sir *Charles Dance*, to run as a public conveyance for passengers between Gloucester and Cheltenham. The locomotive engine was built on by Mr. *Gurney's* principle. It commenced running on the 21st of February, and continued to run four times a day between the two places just mentioned until the 22d of June, the distance being 9 miles. During this time it performed 396 regular journeys, making 3644 miles in all, and carrying upwards of 3000 passengers, without a single accident, at one half of the fares of horse-coaches, and at a greater speed.

“ The undertaking,” said Mr. *Gurney*, “ which had been hitherto regarded as chimerical, now became serious. Men whose interests, real or imaginary, were affected, became alarmed. Agriculturists hastily considered the subject as one calculated to injure them. The public were taken at one half of the fare of horse-coaches, and that public were rapidly becoming converts in its favour. In this state of things, the most gross mis-statements were industriously and extensively circulated respecting the carriage. Under impressions arising from these reports, an immense number of turnpike bills hastily passed both Houses of Parliament, imposing prohibitory tolls upon steam-carriages. In some cases the tolls imposed amounted to 2*l.* at every gate, at others to 2*l.* 8*s.*, and in some to 3*l.* 8*s.* The Cheltenham Road Bill was one of the acts passed amongst the number."

This, however, was not the only way in which this disgraceful conspiracy against the progress of improvement manifested itself. Sir *Charles Dance* states, that objections to his carriages were made by various descriptions of persons, viz. country gentlemen, trustees of roads, farmers, coach proprietors, coachmen, post-boys, &c. &c. Some stated they would injure agriculture, others the roads, others that they would destroy the farmers, others that they would destroy coach proprietors, and throw all the hands employed by them out of work. Understanding that the trustees of the Gloucester and Cheltenham road were urged by the opponents of the undertaking to concoct measures for preventing the carriage from running, Sir *Charles Dance*, on the 20th of June, 1831, addressed a printed letter to the trustees of the Gloucester and

Cheltenham road, pointing out the advantages to be expected from the introduction of steam-carriages. On the 22d, he found that large heaps of stones, 18 inches deep, were laid across the road, about four miles from Gloucester, over which the engine had passed twice with considerable difficulty. It was so unusual a mode of repairing a road, which at that time was in excellent order, and required no repair, that it was impossible to misunderstand the object which those concerned in the transaction had in view. After passing several times over this obstruction, the axletree of the carriage broke; and this circumstance, united with others, and with the passing of the prohibitory toll bill, forced the proprietors of the steamer to abandon their undertaking. The steam-carriage ceased to run accordingly.

" It was represented to me," says Sir *Charles Dance*, " by a great variety of persons, who offered to come forward, that the obstructions on the road were so great and unusual to the stage-coaches, as well as carriages of all descriptions, waggons, carts, &c., and even the mail, that I was urged to represent it to the Post-Master-General to indict the trust, or to take some other legal mode of redress against an act which was generally believed to be wilfully committed for the purpose of obstructing the steam-carriages.

" I was resolved, however, not to do any thing hostile, if possible, and felt only pity and contempt for those who could resort to such means for preventing a great national undertaking. It was my intention to have strengthened my wheels, and to have gone on in spite of any obstructions; but, in the course of the following week, I learnt that a vast number of turnpike bills had passed, and that more were passing through both houses of Parliament, granting tolls upon steam-carriages, which would be a complete prohibition, and that the Cheltenham trust was one of the number. Feeling that we were thus likely to be defeated by acts of the legislature, in addition to the other difficulties, I relinquished my intention of continuing to run the carriages."

Under these circumstances Mr. *Gurney* determined upon petitioning the House of Commons for relief, and a petition was accordingly presented, and a committee appointed to enquire into the subject. The result of the first enquiry of this committee urged them to apply to the House for an extension of their powers, considering the matter worthy of more close and deliberate investigation than was at first contemplated. They sat for three months, during which they examined the highest statistical, scientific, and engineering authorities in the country; and, on the 12th of October, their report, to which we have already frequently referred, was ordered to be printed.

The result of this report was a recommendation to the House to repeal the prohibitory toll bills. The committee also stated, that their enquiries have led them to the belief that the substitution of inanimate for animate power in draught upon common roads is one of the most important improvements in the means of internal communication ever introduced, and *that they considered its practicability to be fully established.*

That its general adoption would take place more or less rapidly in proportion as the attention of scientific men shall be drawn by public encouragement to further improvement. The report also states, that one of the causes of the imposition of excessive tolls *was, a determination on the part of the trustees of roads to obstruct, as much as possible, the use of steam as a propelling power*, and that they recommend that legislative protection should be extended to steam-carriages with the least possible delay. In conclusion, the committee state, that sufficient evidence has been adduced to convince them.

1. "That carriages can be propelled by steam on common roads at an average rate of ten miles per hour.

2. "That at this rate they have conveyed upwards of fourteen passengers.

3. "That their weight, including engine, fuel, water, and attendants, may be under three tons.

4. "That they can ascend and descend hills of considerable inclination with facility and safety.

5. "That they are perfectly safe for passengers.

6. "That they are not (or need not be, if properly constructed) nuisances to the public.

7. "That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

8. "That, as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses.

9. "That rates of toll have been imposed on steam-

carriages, which would prohibit their being used on several lines of road, were such charges permitted to remain unaltered."

The prohibitory toll bills are at the present time (June 1832) in process of being repealed by Parliament, in conformity with the recommendation contained in the above report, and the enterprise of the nation being set free from the trammels which the legislature, deceived and entrapped by the misrepresentations of ignorance and dishonesty, had imposed upon it, will now be once more called into action, and the public will speedily see that, great as the effects of steam have hitherto been upon the prosperity of England, other effects of not less magnitude and importance still remain to be developed. At the moment that I write several steam-carriages are in process of construction for regular work upon the public roads of England. Some are about to be established between Paddington and the Bank, upon the New Road; others between London and Greenwich, and other places in the vicinity of the metropolis. Another, it is stated, is to run between London and Birmingham. The first impulse once received, the progress will be rapid, and the effects of proportionate importance.

It would be foreign to my present object to enter upon any discussion to refute the opinions, and to remove the prejudices which lead various classes of persons to oppose the progress of this great improvement. I must be content, upon this subject, with referring those who are willing to be informed, and who do not desire to continue involved in error, neglecting the means of information which lie open to them, to the evidence given before the committee of the House of Commons upon steam-carriages.

The erroneous opinions entertained by many persons respecting the injurious effects which may be produced by this improvement on the agricultural interests are conclusively refuted in the evidence of Colonel *Torrens.* On the contrary, as he there clearly proves, so far from injuring the agricultural interests, such improvements in the means of transport must materially serve them. Agriculture is prosperous in proportion as the quantity of produce brought to market exceeds the quantity expended in bringing it there. If steam-carriages be employed instead of carriages drawn by horses, it will be because that mode of conveyance is cheaper. Cheapening the transport of produce must necessarily diminish the quantity of produce expended in bringing a given quantity to market, and will, therefore, increase the net surplus which consitutes the encouragement to agriculture. There are many tracts of land which cannot now be cultivated, because the expense of cultivation and transport exceeds the quantity which that expenditure would bring to market; but if you diminish the quantity expended in bringing a given quantity to market, then you obtain a surplus produce from such inferior soils, and, consequently, allow cultivation to be extended over tracts which could not otherwise be tilled. It is a well-known principle, also that every improvement which allows us to cultivate land of a quality which could not previously be cultivated, also enables us to cultivate more highly land already under tillage.

The *sudden* introduction of steam-carriages, were it possible, might produce temporary inconvenience, by the quantity of horses which would thereby become displaced; but this introduction can never be suddenly so extensive as to produce that effect. Meanwhile the beneficial effects upon the profits of trade, produced by the reduction of the cost of transport, must encourage industry and enlarge the demand for labour. The demand for labour depends upon the quantity of food and raw materials which can be cheaply obtained. The displacing of horses by steam-engines will set free more food and more materials, and the demand for labour will, therefore, instead of being diminished, be greatly increased. It has been calculated, that, upon common roads, in Great Britain, the number of horses employed amount to a million; and it is said, that as much land is required for the support of one horse as would sustain eight men. If steam-carriages should supersede horses altogether upon the roads, it would follow therefore that there would be available food, and, a demand for eight millions of additional population; but when it is considered, that, in addition to this, the low price of transport would extend cultivation to inferior descriptions of soil, which are now unproductive, and would further enable us to apply additional labour to soils already under tillage, it may be fairly concluded, that the introduction of elementary power upon common roads, to supersede horses, would ultimately double the population, the wealth, and power of Great Britain.

It has been objected, that there are soils which are capable of producing nothing but what is adapted for the support of horses. To this it may be answered, first, that the total displacement of horses cannot be supposed, and that it will happen unavoidably, that a considerable number must continue to be in use, for the purposes of pleasure as well as in those cases to which, from a variety of causes, steam is inapplicable, and that if there be such land as is capable of only supporting horses, the quantity of such land does not exceed that which would be sufficient for the horses which, at all events, must continue to be required. It is also to be considered, that even were such lands thrown out of cultivation, the persons employed in cultivating them would find a more than equivalent demand from the extended cultivation of other land not of this particular quality: but secondly, the fact of there being any land profitable to cultivate, which is not capable of raising some other produce than oats, for which the increasing population would create a demand, is extremely doubtful.

If the sudden introduction of steam-carriages for the conveyance of passengers should produce a temporary fall in the demand for agricultural produce, other effects would ensue which would compensate the agriculturists for such an injury. As the demand for agricultural produce falls, the price must likewise fall, and that would benefit, partly the labouring class and partly the capitalists—the one by receiving higher real wages, and the other higher profits. This would produce a great encouragement to manufacturing industry. This would naturally lead to an increase in the manufacturing population, and to the amount of capital thus employed. The consequence would be, after some pressure upon the agriculturists, the increased population would create the same demand for agricultural produce which the employment of horses formerly created, so that, on the improbable, nay, impossible, supposition that steam-carriages should never be employed for agricultural purposes, the benefit to the country would still be great, by enabling the country to support an increased industrious population, and to become, even more extensively than at present, the great workshop of the world.

The replacing of horses by mechanical power would have the same effect upon the population and wealth of England, as if the actual extent of the country were to be increased by adding to it as much additional fertile territory as would be equal to the land which supports all the horses now employed upon common roads. Such an addition to the territory of the country would, in the first instance, lower the value of agricultural produce, and be injurious to the proprietors of the former territory; but no person could therefore contend, that to enlarge the country by additional tracts of fertile land would be to injure the public interests, yet it is not less absurd to object to increase the available food for human beings by displacing horses and substituting for them mechanical power. Instead of raising the means of locomotion from the surface of the ground, we draw it from the bowels of the earth. Men are capable of being supported by the one, but cannot derive nourishment from the other.*

*Evidence before the Commons, p. 104.

LECTURE XII.

Mr. Perkins's Inventions — His Steam-gun — Nautical-Steam-engine — Operation of Paddle-wheels — Ineffectual Attempts to feather — Meaning of Horse Power.

(114.) SOME years ago, much public attention was attracted by the experiments of Mr. *Perkins* on steam of an unusually high degree of elasticity. Although it does not appear that he has succeeded to any great extent in reducing his designs to useful practical purposes, yet they evince such boldness and originality of conception, that we should not be justified in passing them without particular notice here.

The boilers of the steam-engines hitherto used served two purposes, namely, vessels for heating the water preparatory to the production of steam, and magazines of the steam so produced for the purpose of working the engine. It occurred to Mr. *Perkins*, that the latter purpose might be dispensed with; and that great advantage would thus be gained, by being enabled to reduce very considerably the dimensions of the boiler, to produce much more powerful vapour, and to diminish in a very high ratio the consumption of fuel. To effect this, instead of having a reservoir or store of accumulated steam ready prepared for the engine, he proposed to generate the steam only as it was required, and to permit no part of the water in the boiler to be converted into steam, except just what was necessary to press the piston at each stroke.

It had been long known that the vaporisation of a liquid could be resisted by mechanical pressure, and that, if so resisted, the liquid would be susceptible of receiving any temperature and yet retaining its liquid form. It was also known, that upon the removal of this pressure, the production of steam of an elastic force proportionate to the pressure would be the inevitable consequence. Mr. *Perkins* availed himself of these facts to carry into effect the design we have thus mentioned. He constructed a cylindrical vessel of copper, 3 inches thick, containing about 8 gallons, and capable of bearing an internal pressure of 4000 lbs. on the square inch. An aperture in the end of this vessel opened into the steam-pipe by a valve loaded with 35 times the pressure of the atmosphere, and a safety-valve was placed on another aperture, loaded with 37 times the atmospheric pressure. At another aperture, a pipe was introduced into this vessel, which communicated with a forcing-pump, by the action of which water could be forced into it. This cylindrical vessel, which was called a generator, was completely filled with water, and was placed vertically in a furnace. The fuel in this furnace was kept in vivid combustion by forcing air through it with bellows; a method found to be much more effectual than the ordinary draught.

The water in the generator not being permitted to expand into vapour, had its temperature raised to 300, 400, or even 500 degrees of the common thermometer. When this was effected, a small quantity of water was forced in by means of the forcing-pump; and since water is an incompressible fluid, an equal quantity was necessarily forced out at the valve loaded with the lesser weight. This water, issuing from the generator into the steam-pipe, instantly expanded, or *flashed* (as he called it) into steam of an enormous pressure, and was thus conducted to the piston, which was worked by it in the ordinary manner of a double-acting engine on *Watt's* principle, condensation being effected on one side, while the steam-pressure was introduced on the other.

The vapour which remained uncondensed he estimated at 5 times the atmospheric pressure; while the steam produced by the water issuing from the generator, and pressing the piston on the other side, was equal to 35 times the atmospheric pressure; so that an effective impelling force was thus obtained equal to 30 times the pressure of the atmosphere, or 450 lbs. on the square inch.

The steam condensed under a pressure of 5 times that of the atmosphere, had a temperature of 350° of the common thermometer; and, at this temperature, was forced into the generator by the forcing-pump, to be again circulated through the machine: thus saving a large quantity of the heat, in the same manner as was accomplished by the hot-water pump and feed-pipe in *Watt's* engine.

The precautions used to prevent accidents from the high pressure to which the apparatus was subject seem to have been sufficient to give every reasonable assurance of safety. Besides that the apparatus itself was constructed to bear about 260 times the atmospheric pressure, there was, as already mentioned, a safety-valve loaded with 37 atmospheres. In addition to this, a tube entered the generator, terminating in a copper ball, which burst with a pressure of 1000 lbs. upon the square inch, being a pressure equal to about 66 times that of the atmosphere. Another tube communicated with an indicator; an instrument which shows the strength of the pressure by means of a spiral ring, similar to the common ouncel.

It has been thought that the bursting of the boiler, or of any part of the apparatus containing water of such an extraordinary temperature, would be attended with considerable danger. This, however, Mr. *Perkins* states to be a mistake; for, in case of such an accident, the water would flow out so fast that it would not receive the quantity of additional heat necessary to convert it into steam; and that the consequence would be, that a very small portion would assume the vaporous form; and the remainder, retaining its liquidity, would extinguish the fire. In case of the copper ball above mentioned bursting, it would tear like paper, without any explosion, or occasioning any injury. Mr. *Perkins* has frequently caused it to burst for the purpose of proving this.

Mr. *Perkins* has attempted, and not without some success, to apply the powers of steam as a substitute for those of gunpowder. His manner of effecting this does not differ materially in its detail from the air-gun; only that, instead of a magazine of condensed air, he uses a generator, containing water heated to such a temperature that, when relieved from pressure, it flashes into steam of prodigious elasticity. Balls are admitted from a hopper into a gun-barrel near the breech, and at the breech a stream of highly elastic steam enters, and blows the ball out of the barrel. The effects of these projectiles are related to be fully equal to those of gunpowder similarly applied; and, besides, they possess the advantage of being capable of being discharged from the same barrel in uninterrupted succession, and for any length of time.

Upon the whole, the practical difficulty which seems to attend the use of steam, in the manner proposed by Mr. *Perkins*, is the maintaining of the power, by keeping a sufficient quantity of water at the unusually high temperature which is requisite for his purposes. Of the actual existence or possibility of obtaining the power there can be no doubt; but unless that power can be sustained, it will avail but little, considered as a mechanical agent.

In his more recent attempts Mr. *Perkins* appears to have abandoned the principle of separating the water from steam, and to have returned to the ordinary method of generating steam in contact with the water. He has lately used tubular boilers, which do not appear to differ very materially from others which have been in use.

(115.) One of the most interesting and important uses of the steam-engine is its application to nautical purposes. There are various ways in which this machine may be used in propelling a vessel through the deep; but that which is now universally adopted, is by giving, through its means, rotation to paddle-wheels placed at the side of the vessel. The engine is placed in the centre of the vessel, between the wheels; and the ascent and descent of the piston is applied to work a crank, by means of which the wheels are turned, and the vessel is propelled by the action of the paddle-boards on the water.

The engine works the crank through the intervention of a beam, in the manner we have already described. In the earlier nautical engines a fly-wheel was used, by the momentum of which the paddle-wheels were turned, when the crank was in that position in which the engine lost its power over it (60); but those of a later period have always two cylinders and pistons worked by the same boiler, and two cranks upon the axle of the paddle-wheels, at right angles to each other; so that at the time when the engine loses its power over one crank it plays with its full effect on the other, and thus the fly-wheel is dispensed with.

Paddle-wheels have been usually made like the common under-shot water-wheel, the paddle-boards being all directed towards the centre, as in fig. 67. This construction seems to be the best when the paddle-boards remain fixed. The efficiency of such a wheel depends on the number of the paddle-boards, the velocity with which the wheel is turned, and the depth to which it is immersed in the water. Experiments have not yet been instituted, so far as we have been informed, which determine these circumstances satisfactorily. It is easy, however, to see that the wheel should not be immersed lower in the water than is sufficient to cover the lowest float-board A; for if more be immersed, a part of the power will be expended in lifting and depressing the water.

It is an established principle, that the action of a plane surface moving in a fluid is always perpendicular to the surface, in whatever direction it may be moved. Now, suppose the wheel immersed to the level L′L, the force of the float-board B on the water is exerted in the direction *a b*, perpendicular to it. This force, by a well-known mechanical principle, is equivalent to the combined action of two forces in the directions of the sides of a parallelogram; one, *a c*, vertical, and the other, *a d*, horizontal. The horizontal element *a d* is effective in propelling, but the vertical part *a c* has a lifting effect on the water, and is therefore lost. In like manner, the force of the paddle-board C is resolved into two, one, *e g*, vertical, and the other, *e h*, horizontal, the latter of which only propels. The forces of the corresponding paddles, B′ C′, on the other side of the lowest paddle, being similarly circumstanced, only having a descending motion instead of an ascending one, the elements *a′ c′*, *e′ g′*, of the forces, which act vertically, will be directed downwards, and will depress the water. These vertical elements of the forces on both sides of the lowest paddle-board have no effect whatever in impelling the vessel, and are therefore so much force expended without any useful effect.

If the wheel be supposed to be immersed below its axle to the level *l l*, owing to its occasionally dipping in the water from the roughness of the sea; the action of the horizontal paddles D′ D is totally lost, their whole force being expended in lifting or depressing; and the actions of the paddles E′ F above these being resolved, like the others, into vertical and horizontal elements, the horizontal elements will have a retarding effect, as is indicated by the direction of the arrows.

It is evident, from inspecting the position of the arrows, which indicate the directions of the horizontal elements of the forces, and also from the length of the sides of the parallelograms, which indicate the magnitudes of these elements, that the more deeply such a wheel as this is immersed, the more force will be lost, in proportion to the force expended. Such a wheel should not, therefore, be immersed to a greater depth than that of the lowest paddle.

Various contrivances have been suggested to avoid the expenditure of force in lifting and depressing the water, and also to remove the back action already mentioned; in other words, it has been attempted to make the paddle-boards *feather* themselves in rising from the water.

In one instance a mechanism was contrived, which, by making each paddle revolve on its axis in the same time as the wheel itself, and in an opposite direction, the paddles were always kept in the vertical position, as in fig. 68. In such a wheel, the back action of the paddles above the axle is increased by exactly as much as the propelling power of those which are below it. Besides this, other practical objections were found to apply to it. In a rough sea, such a wheel presented a surface to the surge which formed a solid breakwater, and produced a liability to fracture and derangement.

Various methods have been invented for feathering the paddles; but they are all more or less subject to the objection of mechanism inconveniently complex, and subject to accidental derangement. Indeed, this is scarcely avoidable in the construction of any moveable paddles; nor do we see any fair prospect of such improvement in the application of steam to navigation, until some means be invented by which the fuel may be economised to a greater extent than now is practised.

(116.) The conventional method of expressing the power of an engine with reference to that of horses was first adopted by Savery, and arose, naturally enough, from the circumstance of the work proposed to be executed by steam-engines having been previously done by horse-mills. It was therefore customary to say that this or that steam-engine would be equivalent to a mill worked by ten or twenty, or any given number of horses. The standard was one with which those for whose use steam-engines were intended were perfectly acquainted, and no method of expressing the power of the machine could have come so home to their familiar notions, nor have been so perfectly appropriate and fair.

A horse's power is, however, to a certain degree, an indefinite standard, since horses vary in strength, one being able to do double the work of another. While, therefore, it would have been very inexpedient to have totally abandoned this universally received and sufficiently well understood standard, it became necessary, as the manufacture of steam-engines increased, to give the standard a more fixed and definite meaning. For this purpose, a horse's power is estimated at so many pounds of water, raised through the height of one foot per minute, the animal being supposed to work for eight hours daily. As to the number of pounds to be thus assigned to a horse's power, engineers have differed. Smeaton estimates the average power of a horse at 22,916 lbs. raised one foot per minute for eight hours a day. Desaguliers makes it 27,500. Messrs. Bolton and Watt caused experiments to be made with the strong horses used in the breweries in London, and from the result of these they assigned 32,000 lbs. as the proper value of a horse's power. This, however, is considered rather above the fair average; but in the estimation of the power of engines, this error operates against the manufacturer and in favour of the purchaser, as it rather underrates the power of the engine.

In estimating the power of an engine, compared with horses, it is supposed only to work for the same time, *i. e.* eight hours daily; whereas the engine has the advantage of being capable of working for twenty-four hours per day. If this were taken into account, the power of an engine would be three times what it is now denominated.

THE END.

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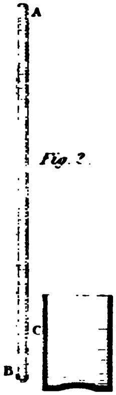
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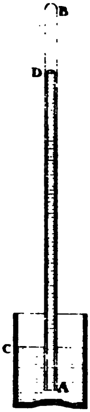

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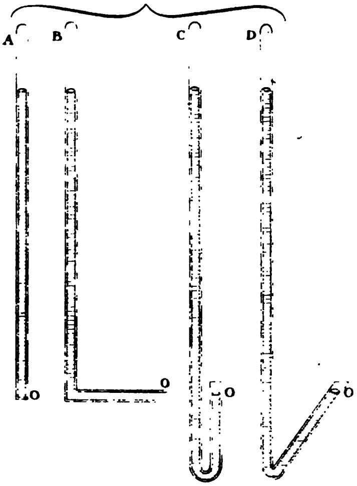

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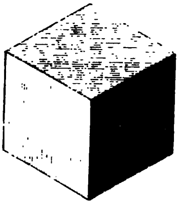

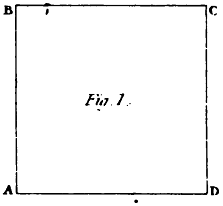
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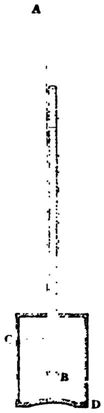

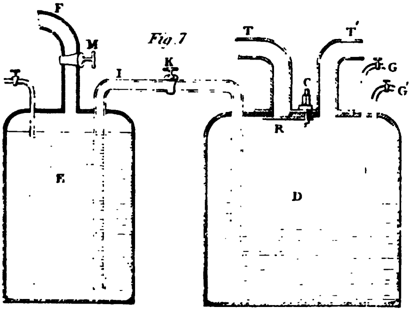
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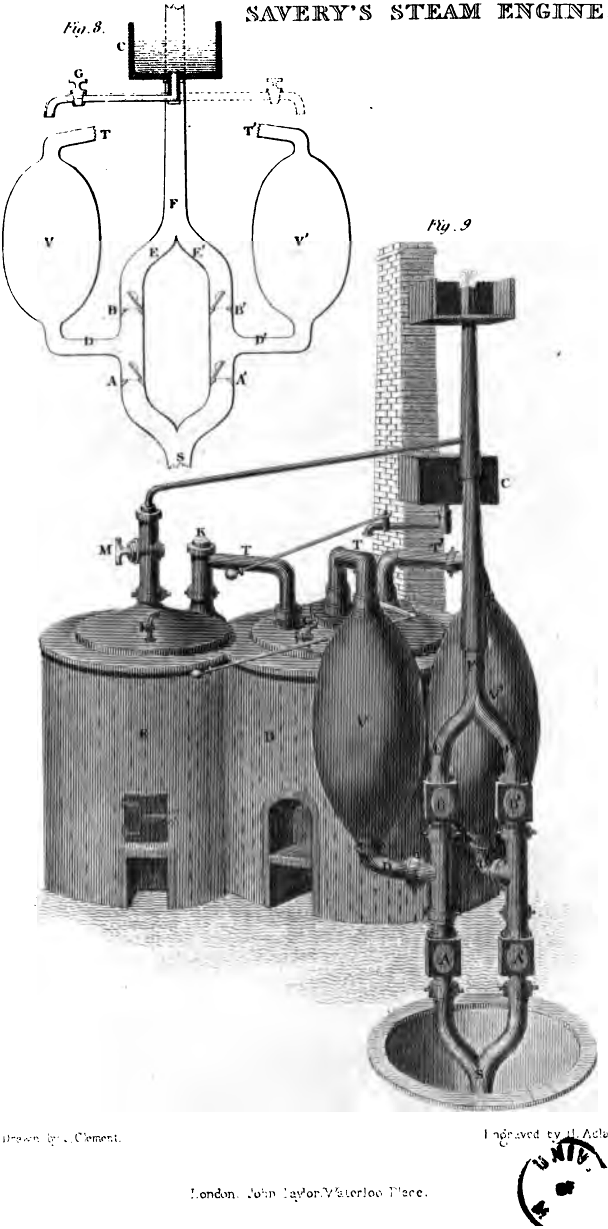

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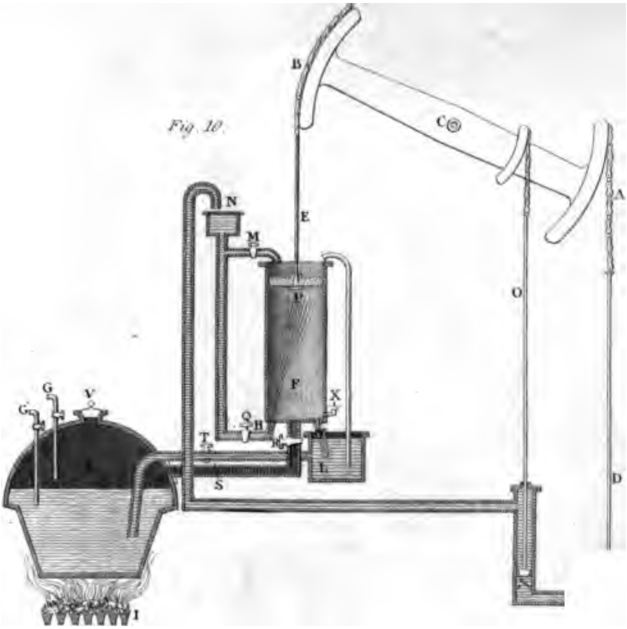

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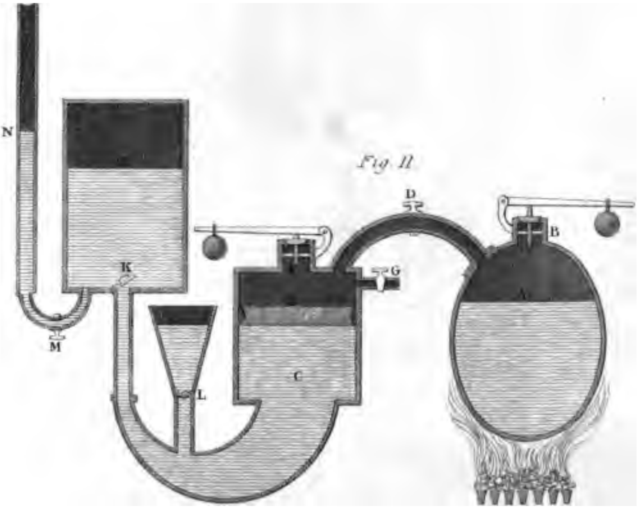

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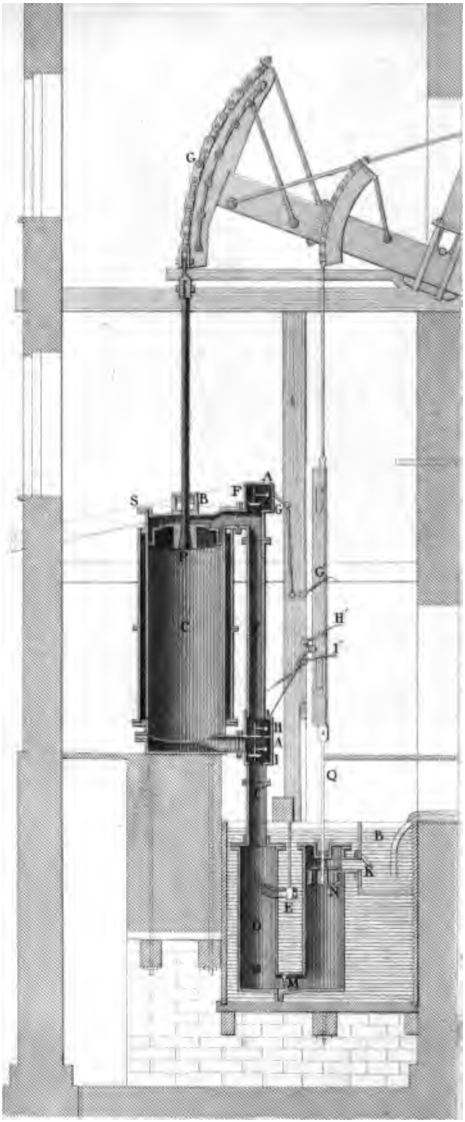

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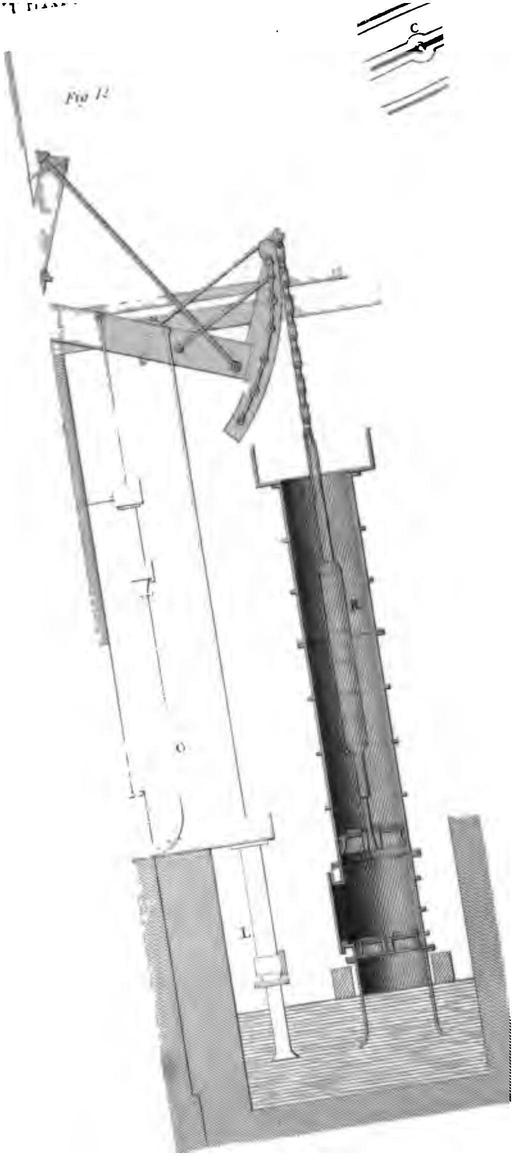

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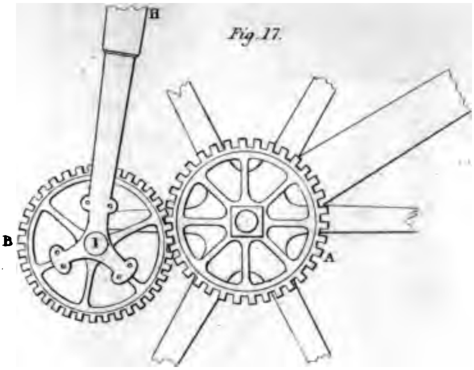

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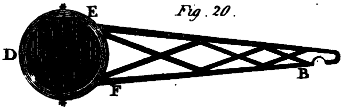

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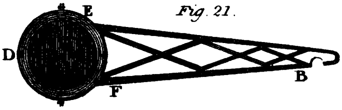

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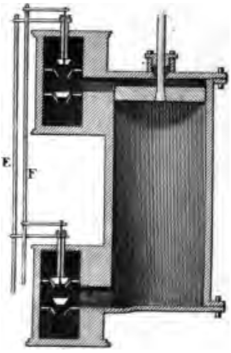

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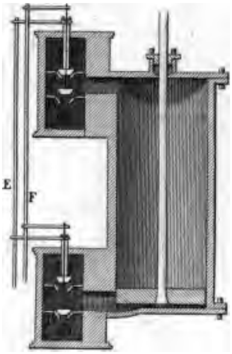

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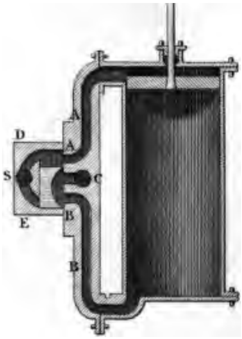

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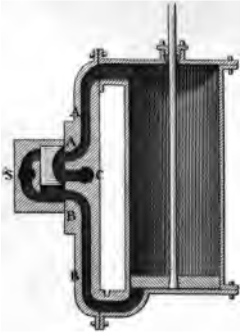

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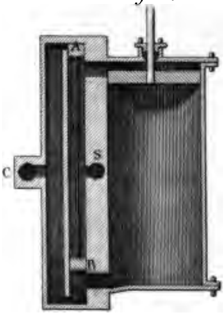

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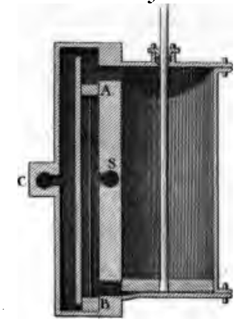

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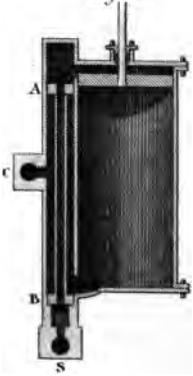

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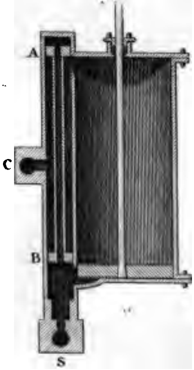

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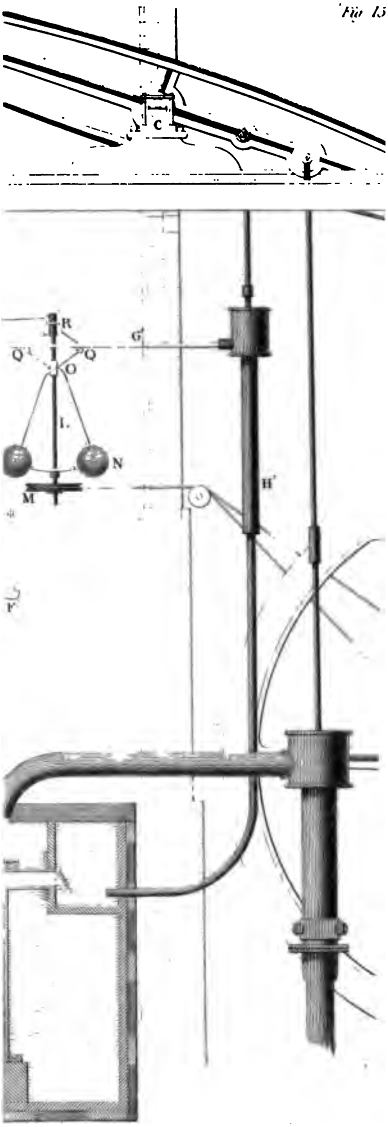

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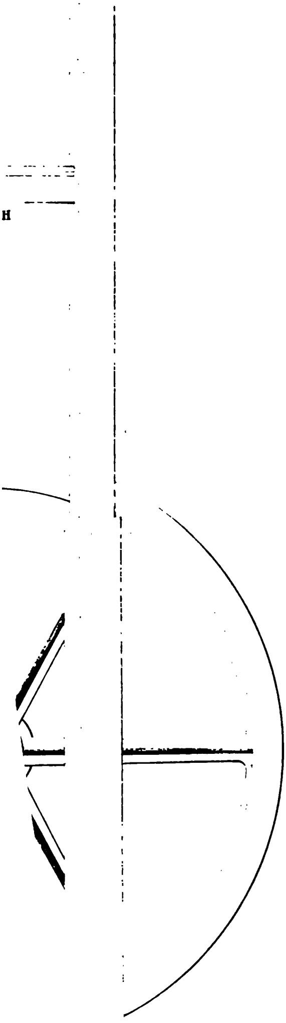

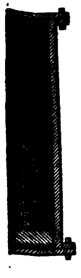

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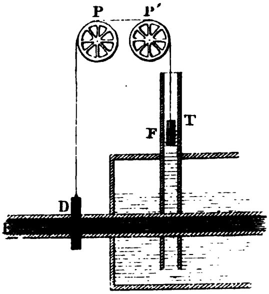

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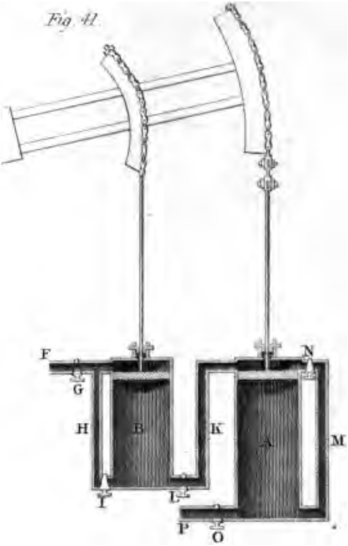

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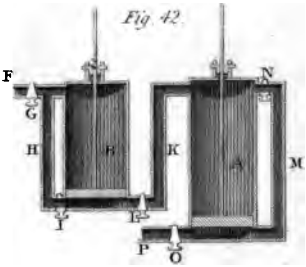

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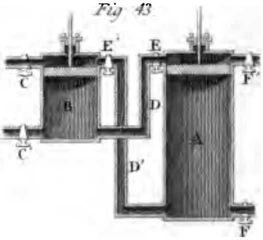

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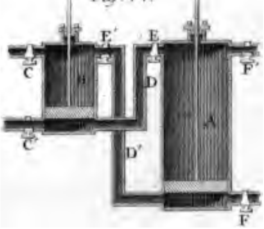

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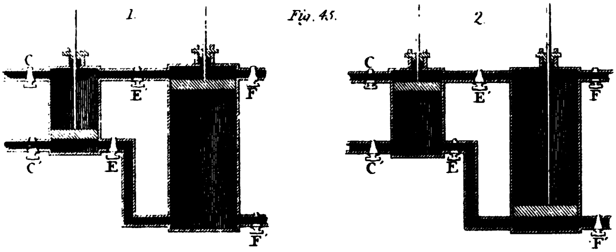

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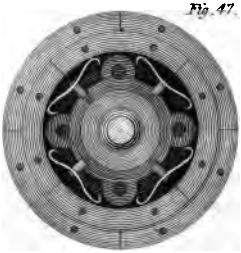

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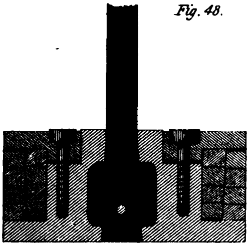

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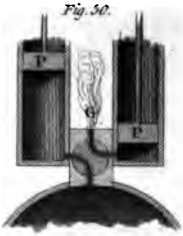

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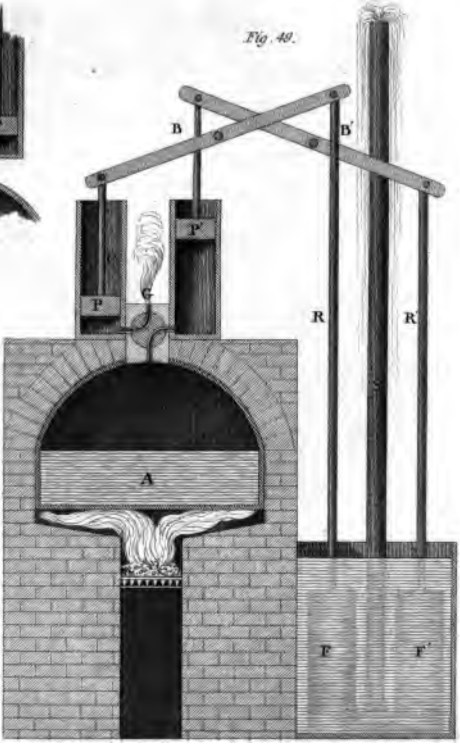

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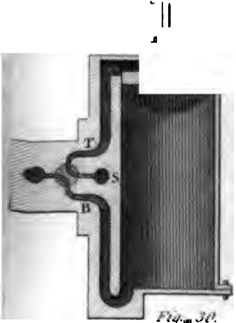

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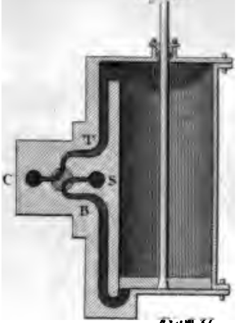

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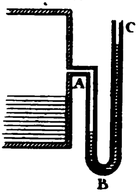

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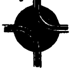

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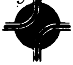

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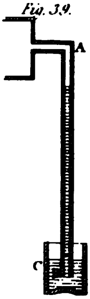

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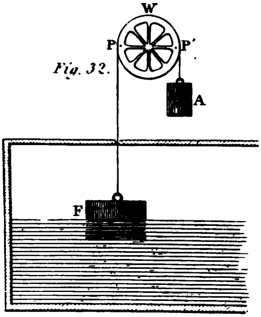

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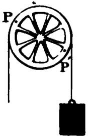

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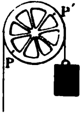

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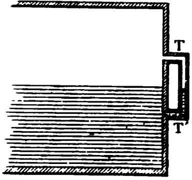

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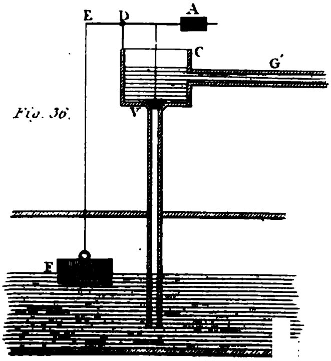

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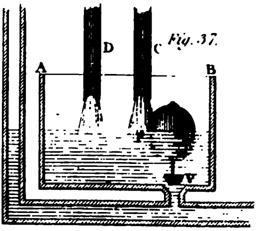

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